State of California
The Resources Agency
Department of Water Resources

FINAL REPORT
EVALUATION OF POTENTIAL EFFECTS OF OROVILLE FACILITIES OPERATIONS ON SPAWNING CHINOOK SALMON
SP-F10, TASK 2B

Oroville Facilities Relicensing
FERC Project No. 2100

MARCH 2004

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Oroville Facilities Relicensing FERC Project No. 2100

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REPORT SUMMARY

The original objective of Task 2B of Study Plan (SP) F10 was to evaluate the timing, magnitude, and frequency of flows on the spawning distribution, and evaluate the potential project effects on salmonids in the lower Feather River from the Fish Barrier Dam downstream to Honcut Creek. A review of available river flow data for the lower Feather River indicated that during the spawning season, in both the Low Flow Channel (LFC) and the High Flow Channel (HFC), river flows were relatively constant with little variation. The purpose of Task 2B was re-scoped to evaluate the effects of the Oroville Facilities operational procedures on spawning Chinook salmon in the lower Feather River. In addition, project effects on spawning steelhead were addressed in a separate task. Operations of the Oroville Facilities affect water temperature, instream flow, and water surface elevation in the lower Feather River which, in turn, influence spawning Chinook salmon. The results from this study would be used to evaluate future potential resource actions involving facility operations and potential effects to spawning Chinook salmon.

Carcass survey data from 2000 through 2003 were analyzed to determine the temporal and spatial distributions, as well as other characteristics, of spawning Chinook salmon in the lower Feather River from the Fish Barrier Dam (river mile [RM] 67.25) downstream to Gridley Bridge (RM 51). The spawning period was defined as August 12 through December 19. An extensive literature review was conducted to determine appropriate water temperature index values to use as technical evaluation guidelines to assess the potential thermal impacts from operation of the Oroville Facilities to spawning Chinook salmon. In general, water temperatures in the LFC appear to be suitable during the spawning and embryo incubation life stage. High water temperatures in the HFC from August through late September may have adverse impacts, particularly on the earlier spawning spring-run Chinook salmon.

Combined results from the carcass surveys from 2000 through 2003 showed that 5.6 percent of inspected Chinook salmon carcasses had a clipped adipose fin. The highest percentages of adipose fin clipped carcasses were detected during September, in the LFC. The heads from 439 adipose fin clipped carcasses from the 2002 survey were processed, and 80.8 percent contained a coded wire tag (CWT). Decoding the CWTs indicated that 96.6 percent of the sample originated from Feather River stock, with a 3.4 percent straying rate into the Feather River from salmon originating from non-Feather River stock. Overlap in carcass detection dates between spring-run and fall-run (run origin was designated at release) Chinook salmon occurred from September 3 through October 17. In 2002, 81.1 percent of all carcasses were detected in the LFC, and the highest carcass counts in the LFC occurred from October 14 through October 31 with the peak occurring October 21 through October 25. In the HFC in 2002, the highest carcass counts occurred from November 11 through November 21. In 2002, spawning activities in the lower Feather River likely began between August 13 and September 3, 2002. Water temperatures in the LFC and HFC, during this period, averaged 58.3^{o}F (14.6^{o}C) and 65.4^{o}F (18.6^{o}C), respectively. Spawning escapement estimates from 2000 through 2003 were highest in the LFC, and estimates for both reaches were much

higher than historical averages, particularly for 2001. PHABSIM modeling predicted that spawning habitat availability would be maximized in the LFC and HFC at flows of 700 to 725 cubic feet per second (cfs) and 1,500 cfs, respectively. The weighted useable area (WUA) index value at the constant flow of 600 cfs in the LFC during the spawning period was 97 percent of the maximum value. From 2000 through 2003, flows during the spawning period in the HFC ranged from 1,200 to 7,000 cfs, corresponding with approximately 20 percent to 95 percent of the maximum WUA index value. The 1995 superimposition indices (SIs) suggest there is insufficient available spawning habitat in the LFC, but adequate available spawning habitat in the HFC. The 2003 SIs suggest there is insufficient available spawning habitat in the LFC and in the HFC. Because spawning habitat is finite, high Chinook salmon return rates may have caused spawning substrates to be heavily utilized in the 2003 spawning season.

Pre-spawn mortality estimates in the lower Feather River from 2000 through 2003 were high. During this period, annual pre-spawn mortality rates in the LFC and HFC averaged 42.5 percent and 39.7 percent, respectively. Pre-spawn mortality estimates were particularly high during September. Combining all years and both reaches, pre-spawn mortality estimates during September ranged from 70 to 100 percent. However, an average of approximately five percent (ranging from 2.8 percent to 8.1 percent) of the total annual spawning population from 2000 through 2003 spawned during September. A combination of stress from water temperature, river flows, disease, high spawning returns, and recreational angling likely account for the high pre-spawn mortality estimates in the lower Feather River from 2000 through 2003.

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1.0 INTRODUCTION

The original objective of Task 2B of Study Plan (SP) F10 was to evaluate the timing, magnitude, and frequency of flows on the spawning distribution, and to evaluate the potential project effects on salmonids in the lower Feather River from the Fish Barrier Dam downstream to Honcut Creek. A review of available flow data for the Feather River indicated that during the spawning season, in both the LFC and the HFC, flows were relatively constant with little variation. Based on available flow data, Task 2B was re-scoped to evaluate the effects of operation of the Oroville Facilities on spawning Chinook salmon in the lower Feather River. In addition, project effects on spawning steelhead were addressed in a separate task. The results of this study would be used to evaluate future potential Resource Actions involving project operations and potential effects to spawning Chinook salmon.

1.1 BACKGROUND INFORMATION

Ongoing operation of the Oroville Facilities has the potential to influence spawning Chinook salmon in the lower Feather River. Operations of the Oroville Facilities affect water temperature, instream flow, and water surface elevation in the lower Feather River which, in turn, influences spawning Chinook salmon. As a component of SP-F10, "*Evaluation of Project Effects on Salmonids and their Habitat in the Feather River Below the Fish Barrier Dam,"* Task 2 evaluates project effects on the spawning and incubation period of salmonids in the lower Feather River. Task 2B, herein, evaluates the potential effects of project operations on spawning Chinook salmon.

Minimum flows in the lower Feather River were established in the August 1983 agreement between the California Department of Water Resources (DWR) and the California Department of Fish and Game (DFG) (DWR 1983). The agreement established criteria for flow and water temperature in both the LFC and HFC. The agreement specified that DWR release a minimum of 600 cfs into the lower Feather River from the Thermalito Diversion Dam for fisheries purposes. Therefore, the reach of the lower Feather River extending from the Fish Barrier Dam to the Thermalito Afterbay Outlet, also known as the LFC, is operated at 600 cfs year round, with variations in flow occurring infrequently. Most flow deviations from 600 cfs in the LFC occur during flood control releases, in the summer to satisfy downstream water temperature requirements for salmonids, or for maintenance and monitoring purposes.

1.1.1 Statutory/Regulatory Requirements

The purpose of Task 2B of Study Plan (SP)-F10 is to evaluate the effects of Oroville Facilities operational procedures on spawning Chinook salmon in the lower Feather River from the Fish Barrier Dam downstream to Gridley Bridge. Salmonids present in the lower Feather River include spring-run Chinook salmon (*Oncorhynchus tshawytscha*), fall-run Chinook salmon (*O. tshawytscha*), and steelhead (*O. mykiss*). On September 16, 1999, naturally-spawned Central Valley spring-run Chinook salmon were listed as threatened under the federal ESA by the Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service (NOAA Fisheries) (NOAA Fisheries 1999). The Central Valley spring-run Chinook salmon Evolutionarily Significant Unit (ESU) includes all naturally-spawned populations of spring-run Chinook salmon in the Sacramento River and its tributaries, which includes naturally spawned spring-run Chinook salmon in the lower Feather River (NOAA Fisheries 1999). On March 19, 1998, naturally-spawned Central Valley steelhead were listed as threatened under the federal ESA by NOAA Fisheries (NOAA Fisheries 1998). The Central Valley steelhead ESU includes all naturally-spawned populations of steelhead in the Sacramento and San Joaquin rivers and their tributaries, which includes naturally spawned steelhead in the lower Feather River (NOAA Fisheries 1998).

In addition to the ESA, Section 4.51(f)(3) of 18 CFR requires reporting certain types of information in the Federal Energy Regulatory Commission (FERC) application for license of major hydropower projects, including a discussion of the fish, wildlife, and botanical resources in the vicinity of the project (FERC 2001). The discussion is required to identify the potential impacts of the project on these resources, including a description of any anticipated continuing impact from on-going and future operations. As a subtask of SP-F10, "*Evaluation of Project Effects on Salmonids and their Habitat in the Feather River Below the Fish Barrier Dam*," Task 2B fulfills a portion of the FERC application requirements by describing the relationship between flows and salmonid spawning distributions in the lower Feather River downstream from the Fish Barrier Dam. In addition to fulfilling statutory requirements, the conclusions from this analysis may be used as the basis for developing or evaluating potential Resource Actions focused on providing appropriate flow regimes in the lower Feather River for spawning salmonids.

1.1.2 Study Area

1.1.2.1 Description

The study area in which the results of Task 2B of SP-F10 apply includes the reach of the lower Feather River extending from the Fish Barrier Dam at RM 67.25 downstream to the Gridley Bridge at RM 51 (Figure 1.1-1). The majority of spawning habitat available in the lower Feather River is located in this area. Two distinct reaches exist within the study area: the upstream reach, and the downstream reach. The upstream reach extends from the Fish Barrier Dam downstream to the Thermalito Afterbay Outlet (RM 59), and is referred to as the LFC. The downstream reach extends from the Thermalito Afterbay Outlet downstream to the confluence with the Sacramento River (RM 0), and is referred to as the HFC. For purposes of this report, the HFC extends from the Thermalito Afterbay Outlet downstream to the Gridley Bridge. The flow regimes associated with each reach are distinct, and are summarized below.

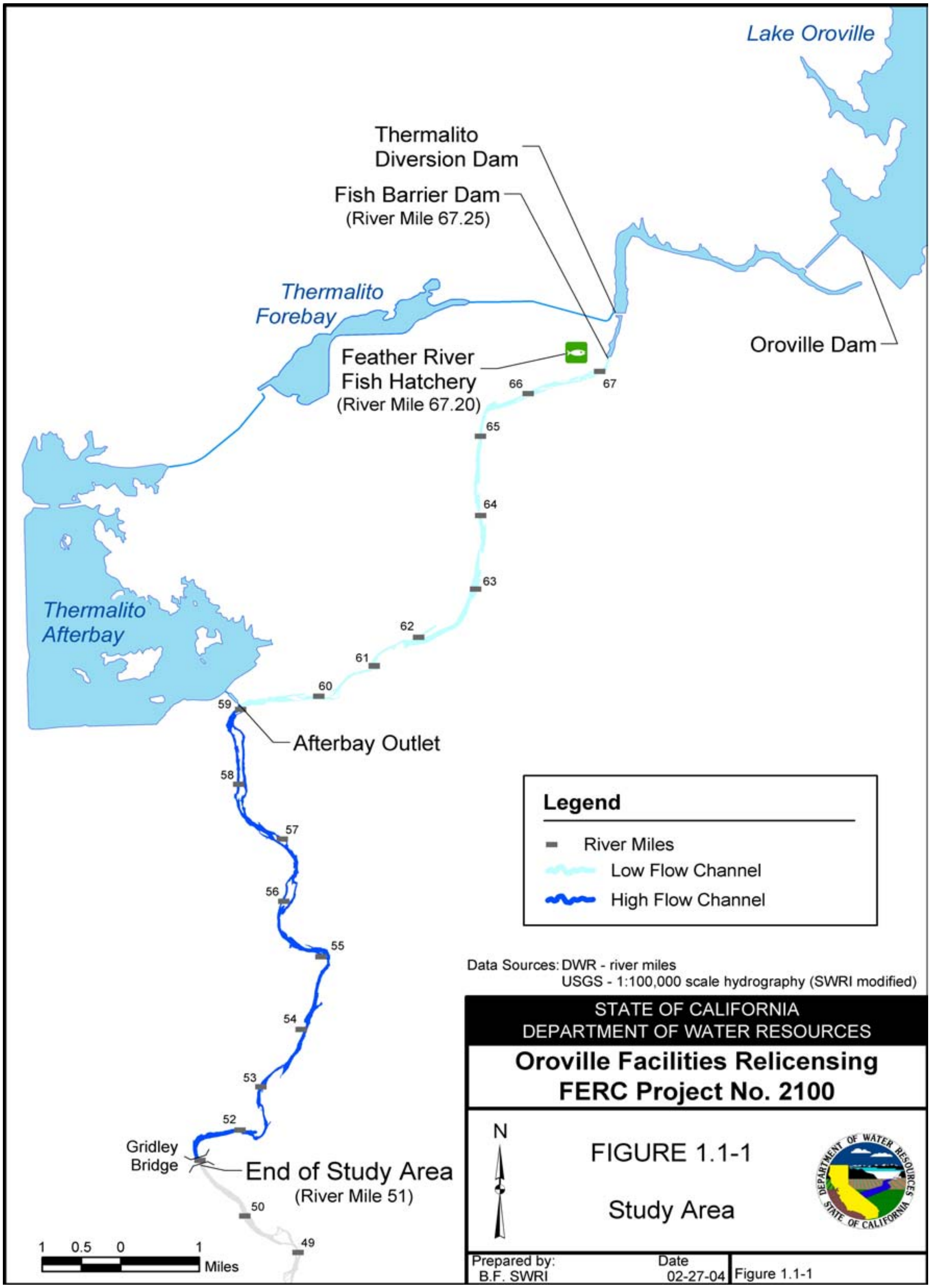


Figure 1.1-1. Study area.

1.1.2.2 History

Flow requirements for the lower Feather River were determined by the August 26, 1983 agreement between DWR and DFG titled "*Agreement Concerning the Operation of the Oroville Division of State Water Project for Management of Fish & Wildlife.*" The agreement states that a flow of 600 cfs is to be released into the main channel of the lower Feather River from the Thermalito Diversion Dam (i.e. diversion dam outlet, diversion dam power plant, and the Feather River Fish Hatchery pipeline) for fishery purposes. In the reach of the lower Feather River downstream of the Thermalito Afterbay Outlet, flow is supplemented by releases from the Thermalito Afterbay Outlet to maintain a minimum flow downstream to the mouth of the Feather River. During the month of September, the flow requirement in the reach of the lower Feather River extending downstream from the Thermalito Afterbay Outlet is 1,000 cfs. During the months of October through February, the minimum flow requirements for this reach are 1,200 cfs or 1,700 cfs, depending on the percentage of unimpaired runoff of the Feather River near Oroville from the preceding water year as compared to the normal unimpaired runoff of 1,942,000 acre-feet (af) (mean of 1911-1960). Additionally, if the highest average one hour flow of the combined project releases exceeds 2,500 cfs between October 15 and November 30, with the exception of releases for flood control, accidents, project failure, and major or unusual maintenance, then the minimum flow from October through March shall not be less than 500 cfs of the highest average one hour flow. The 2,500 cfs threshold was implemented to protect redds should spawning occur in the overbank areas. From October through February, if the minimum flow is 1,700 cfs, then flows must remain at 1,700 cfs through March, and if the minimum flow is 1,200 cfs, then the flow requirement is 1,000 cfs in March. The project is usually operated such that only one major reduction in flow occurs downstream from Thermalito Afterbay Outlet during the months in which Chinook salmon are spawning and redds may be present in the lower Feather River (generally just before October 15).

1.2 DESCRIPTION OF FACILITIES

The Oroville Facilities were developed as part of the State Water Project (SWP), a water storage and delivery system consisting of reservoirs, aqueducts, power plants, and pumping plants. The main purpose of the SWP is to store and distribute water to supplement the needs of urban and agricultural water users in northern California, the San Francisco Bay area, the San Joaquin Valley, and southern California. The Oroville Facilities are also operated for flood control management, power generation, water quality improvement in the Delta, recreational opportunities, and fish and wildlife enhancement.

FERC Project No. 2100 encompasses 41,100 acres and includes Oroville Dam and Reservoir, three power plants (Hyatt Pumping-Generating Plant, Thermalito Diversion Dam Power Plant, and Thermalito Pumping-Generating Plant), Thermalito Diversion Dam, the Feather River Fish Hatchery and Fish Barrier Dam, Thermalito Power Canal, Oroville Wildlife Area (OWA), Thermalito Forebay and Forebay Dam, Thermalito Afterbay and Afterbay Dam, and transmission lines, as well as a number of recreational facilities. An overview of these facilities is provided on Figure 1.2-1. The Oroville Dam, along with two small saddle dams, impounds Lake Oroville, a 3.5-million-acre-feet (maf) capacity storage reservoir with a surface area of 15,810 acres at its normal maximum operating level.

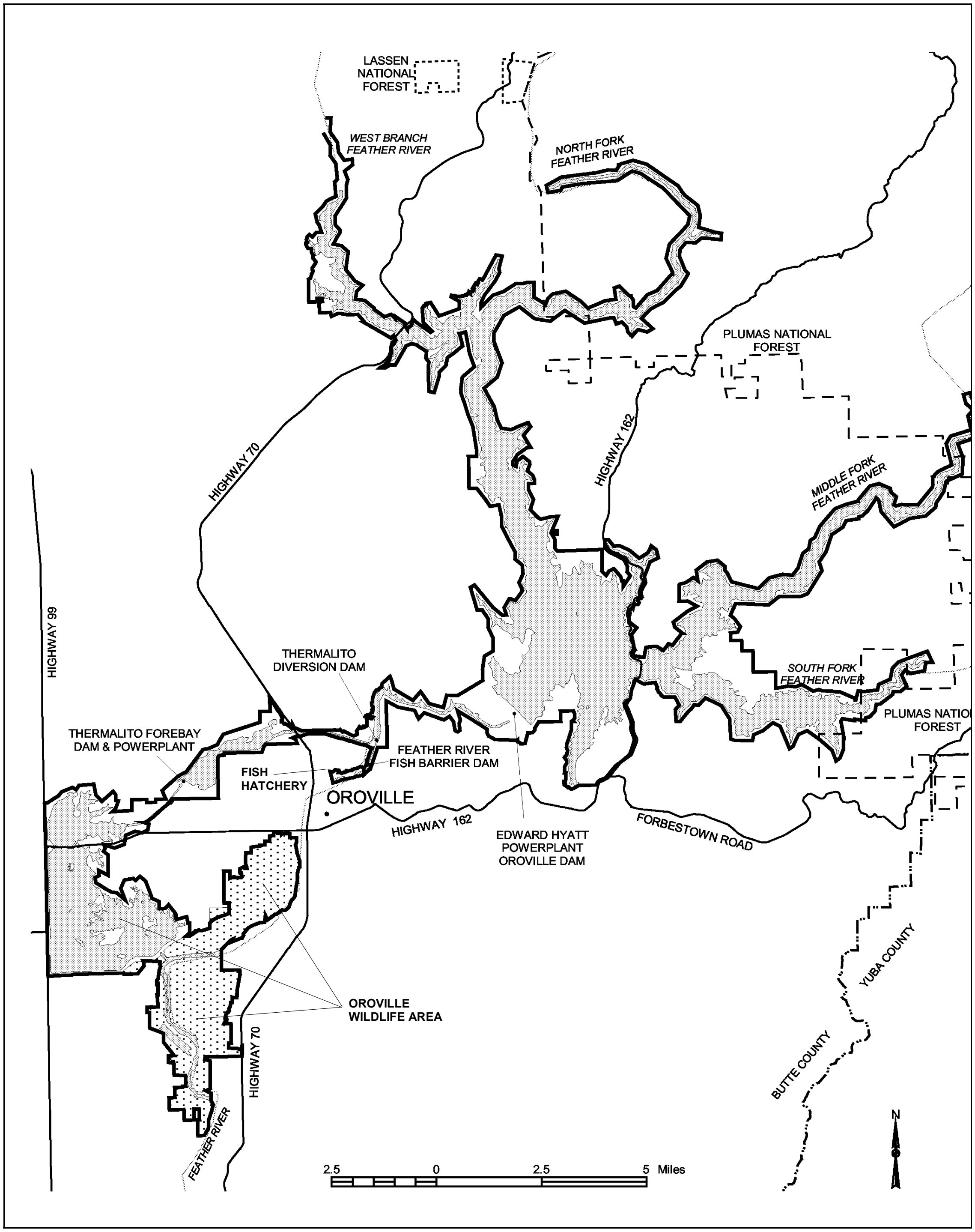


Figure 1.2-1. Oroville Facilities FERC project boundary.

The hydroelectric facilities have a combined licensed generating capacity of approximately 762 megawatts (MW). The Hyatt Pumping-Generating Plant is the largest of the three power plants with a capacity of 645 MW. Water from the six-unit underground power plant (three conventional generating and three pumping-generating units) is discharged through two tunnels into the Feather River just downstream of Oroville Dam. The plant has a generating and pumping flow capacity of 16,950 cfs and 5,610 cfs, respectively. Other generation facilities include the 3-MW Thermalito Diversion Dam Power Plant and the 114-MW Thermalito Pumping-Generating Plant.

Thermalito Diversion Dam, four miles downstream of the Oroville Dam, creates a tail water pool for the Hyatt Pumping-Generating Plant and is used to divert water to the Thermalito Power Canal. The Thermalito Diversion Dam Power Plant is a 3-MW power plant located on the left abutment of the Diversion Dam. The power plant releases a maximum of 615 cfs of water into the river.

The Power Canal is a 10,000-foot-long channel designed to convey generating flows of 16,900 cfs to the Thermalito Forebay and pump-back flows to the Hyatt Pumping-Generating Plant. The Thermalito Forebay is an off-stream regulating reservoir for the 114-MW Thermalito Pumping-Generating Plant. The Thermalito Pumping-Generating Plant is designed to operate in tandem with the Hyatt Pumping-Generating Plant and has generating and pump-back flow capacities of 17,400 cfs and 9,120 cfs, respectively. When in generating mode, the Thermalito Pumping-Generating Plant discharges into the Thermalito Afterbay, which is contained by a 42,000-foot-long earth-fill dam. The Afterbay is used to release water into the Feather River downstream of the Oroville Facilities, helps regulate the power system, provides storage for pump-back operations, and provides recreational opportunities. Several local irrigation districts receive water from the Afterbay.

The Feather River Fish Barrier Dam is downstream of the Thermalito Diversion Dam and immediately upstream of the Feather River Fish Hatchery. The flow over the dam maintains fish habitat in the low-flow channel of the Feather River between the dam and the Afterbay outlet, and provides attraction flow for the hatchery. The hatchery was intended to compensate for spawning grounds lost to returning salmon and steelhead from the construction of Oroville Dam. The hatchery can accommodate an average of 15,000 to 20,000 adult fish annually.

The Oroville Facilities support a wide variety of recreational opportunities. They include: boating (several types), fishing (several types), fully developed and primitive camping (including boat-in and floating sites), picnicking, swimming, horseback riding, hiking, off-road bicycle riding, wildlife watching, hunting, and visitor information sites with cultural and informational displays about the developed facilities and the natural environment. There are major recreation facilities at Loafer Creek, Bidwell Canyon, the Spillway, North and South Thermalito Forebay, and Lime Saddle. Lake Oroville has two full-service marinas, five car-top boat launch ramps, ten floating campsites, and seven dispersed floating toilets. There are also recreation facilities at the Visitor Center and the OWA.

The OWA comprises approximately 11,000 acres west of Oroville that is managed for wildlife habitat and recreational activities. It includes the Thermalito Afterbay and surrounding lands (approximately 6,000 acres) along with 5,000 acres adjoining the Feather River. The 5,000 acre area straddles 12 miles of the Feather River, which includes willow and cottonwood lined ponds, islands, and channels. Recreation areas include dispersed recreation (hunting, fishing, and bird watching), plus recreation at developed sites, including Monument Hill day use area, model airplane grounds, three boat launches on the Afterbay and two on the river, and two primitive camping areas. California Department of Fish and Game's (DFG) habitat enhancement program includes a wood duck nest-box program and dry land farming for nesting cover and improved wildlife forage. Limited gravel extraction also occurs in a number of locations.

1.3 CURRENT OPERATIONAL CONSTRAINTS

Operation of the Oroville Facilities varies seasonally, weekly and hourly, depending on hydrology and the objectives DWR is trying to meet. Typically, releases to the Feather River are managed to conserve water while meeting a variety of water delivery requirements, including flow, temperature, fisheries, recreation, diversion and water quality. Lake Oroville stores winter and spring runoff for release to the Feather River as necessary for project purposes. Meeting the water supply objectives of the SWP has always been the primary consideration for determining Oroville Facilities operation (within the regulatory constraints specified for flood control, in-stream fisheries, and downstream uses). Power production is scheduled within the boundaries specified by the water operations criteria noted above. Annual operations planning is conducted for multi-year carry over. The current methodology is to retain half of the Lake Oroville storage above a specific level for subsequent years. Currently, that level has been established at 1,000,000 af; however, this does not limit draw down of the reservoir below that level. If hydrology is drier than expected or requirements greater than expected, additional water would be released from Lake Oroville. The operations plan is updated regularly to reflect changes in hydrology and downstream operations. Typically, Lake Oroville is filled to its maximum annual level of up to 900 feet above mean sea level (msl) in June and then can be lowered as necessary to meet downstream requirements, to its minimum level in December or January. During drier years, the lake may be drawn down more and may not fill to the desired levels the following spring. Project operations are directly constrained by downstream operational constraints and flood management criteria as described below.

1.3.1 Downstream Operation

An August 1983 agreement between DWR and DFG titled, "*Agreement Concerning the Operation of the Oroville Division of the State Water Project for Management of Fish & Wildlife*," sets criteria and objectives for flow and temperatures in the low flow channel and the reach of the Feather River between Thermalito Afterbay and Verona. This agreement: (1) establishes minimum flows between Thermalito Afterbay Outlet and Verona which vary by water year type; (2) requires flow changes under 2,500 cfs to be reduced by no more than 200 cfs during any 24-hour period, except for flood management, failures, etc.; (3) requires flow stability during the peak of the fall-run Chinook spawning season; and (4) sets an objective of suitable temperature conditions during the fall months for salmon and during the later spring/summer for shad and striped bass.

1.3.1.1 Instream Flow Requirements

The Oroville Facilities are operated to meet minimum flows in the lower Feather River as established by the 1983 agreement (see above). The agreement specifies that Oroville Facilities release a minimum of 600 cfs into the Feather River from the Thermalito Diversion Dam for fisheries purposes. This is the total volume of flows from the diversion dam outlet, diversion dam power plant, and the Feather River Fish Hatchery pipeline.

Generally, the instream flow requirements below Thermalito Afterbay are 1,700 cfs from October through March, and 1,000 cfs from April through September. However, if runoff for the previous April through July period is less than 1,942,000 af (i.e., the 1911-1960 mean unimpaired runoff near Oroville), the minimum flow can be reduced to 1,200 cfs from October to February, and 1,000 cfs for March. A maximum flow of 2,500 cfs is maintained from October 15 through November 30 to prevent spawning in overbank areas that might become de-watered.

1.3.1.2 Water Temperature Requirements

The Diversion Pool provides the water supply for the Feather River Fish Hatchery. The hatchery objectives are 52°F for September, 51°F for October and November, 55°F for December through March, 51°F for April through May 15, 55°F for last half of May, 56°F for June 1-15, 60°F for June 16 through August 15, and 58°F for August 16-31. A temperature range of plus or minus 4°F is allowed for the objectives extending from April through November.

There are several temperature objectives for the Feather River downstream of the Afterbay Outlet. During the fall months, after September 15, the temperatures must be suitable for fall-run Chinook salmon. From May through August, they must be suitable for shad, striped bass, and other warmwater fish.

The National Marine Fisheries Service has also established an explicit criterion for steelhead and spring-run Chinook salmon. Memorialized in a biological opinion on the effects of the Central Valley Project and SWP on Central Valley spring-run Chinook salmon and steelhead as a reasonable and prudent measure, DWR is required to maintain daily average water temperature of <65°F at Feather River Mile 61.6 (Robinson Riffle in the low flow channel) from June 1 through September 30. The requirement is not intended to preclude pump-back operations at the Oroville Facilities needed to assist the State of California with supplying energy during periods when the California ISO anticipates a Stage 2 or higher alert.

The hatchery and river water temperature objectives sometimes conflict with temperatures desired by agricultural diverters. Under existing agreements, DWR provides water for the Feather River Service Area (FRSA) contractors. The contractors claim a need for warmer water during spring and summer for rice germination and growth (i.e., 65°F from approximately April through mid May, and 59°F during the remainder of the growing season). There is no obligation for DWR to meet the rice water temperature goals. However, to the extent practical, DWR does use its operational flexibility to accommodate the FRSA contractor's temperature goals.

1.3.1.3 Water Diversions

Monthly irrigation diversions of up to 190,000 (July 2002) af are made from the Thermalito Complex during the May through August irrigation season. Total annual entitlement of the Butte and Sutter County agricultural users is approximately 1 maf. After meeting these local demands, flows into the lower Feather River continue into the Sacramento River and into the Sacramento-San Joaquin Delta. In the northwestern portion of the Delta, water is pumped into the North Bay Aqueduct. In the south Delta, water is diverted into Clifton Court Forebay where the water is stored until it is pumped into the California Aqueduct.

1.3.1.4 Water Quality

Flows through the Delta are maintained to meet Bay-Delta water quality standards arising from DWR's water rights permits. These standards are designed to meet several water quality objectives such as salinity, Delta outflow, river flows, and export limits. The purpose of these objectives is to attain the highest water quality, which is reasonable, considering all demands being made on the Bay-Delta waters. In particular, they protect a wide range of fish and wildlife including Chinook salmon, Delta smelt, striped bass, and the habitat of estuarine-dependent species.

1.3.2 Flood Management

The Oroville Facilities are an integral component of the flood management system for the Sacramento Valley. During the wintertime, the Oroville Facilities are operated under flood control requirements specified by the U.S. Army Corps of Engineers (USACE). Under these requirements, Lake Oroville is operated to maintain up to 750,000 af of storage space to allow for the capture of significant inflows. Flood control releases are based on the release schedule in the flood control diagram or the emergency spillway release diagram prepared by the USACE, whichever requires the greater release. Decisions regarding such releases are made in consultation with the USACE.

The flood control requirements are designed for multiple use of reservoir space. During times when flood management space is not required to accomplish flood management objectives, the reservoir space can be used for storing water. From October through March, the maximum allowable storage limit (point at which specific flood release would have to be made) varies from about 2.8 to 3.2 maf to ensure adequate space in Lake Oroville to handle flood flows. The actual encroachment demarcation is based on a wetness index, computed from accumulated basin precipitation. This allows higher levels in the reservoir when the prevailing hydrology is dry while maintaining adequate flood protection. When the wetness index is high in the basin (i.e., wetness in the watershed above Lake Oroville), the flood management space required is at its greatest amount to provide the necessary flood protection. From April through June, the maximum allowable storage limit is increased as the flooding potential decreases, which allows capture of the higher spring flows for use later in the year. During September, the maximum allowable storage decreases again to prepare for the next flood season. During flood events, actual storage may encroach into the flood reservation zone to prevent or minimize downstream flooding along the Feather River.

2.0 NEED FOR STUDY

Task 2B is a subtask of SP-F10, "*Evaluation of Project Effects on Salmonids and their Habitat in the Feather River below the Fish Barrier Dam*" that fulfills a portion of the FERC application requirements by evaluating project operations and associated effects to spawning Chinook salmon in the lower Feather River. In addition to fulfilling statutory requirements, information collected during this task may be used in developing or evaluating potential Resource Actions.

The original objective of Task 2B of Study Plan (SP)-F10 was to evaluate the timing, magnitude, and frequency of flows on the spawning distribution, and to evaluate the potential project effects on salmonids in the lower Feather River from the Fish Barrier Dam down to Honcut Creek. A review of flow data from 2000 through 2003 in the lower Feather River indicated that during the spawning season, in both the LFC and the HFC, instream flows were relatively constant with little variation (Figure 2.1-1). Because of relatively constant flow regime during the study period, the effects of flow fluctuations on spawning will be excluded from this report. In addition, project effects on spawning steelhead were addressed in a separate task (for further discussion see section 2.1). The purpose of Task 2B was re-scoped to evaluate the effects of Oroville Facilities operations on spawning Chinook salmon in the lower Feather River.

Potential effects of ongoing project operations in the lower Feather River include alterations to flow, water temperature, floodplain habitat, instream habitat, shaded riverine aquatic (SRA) habitat, coarse sediment supply, and other in-river conditions. Such changes to these habitat characteristics and conditions can influence the various life stages (e.g., adult immigration and holding, spawning and incubation, rearing and emigration) of salmonids. Section 5.51(f)(3) of 18 CFR requires reporting of certain types of information in the FERC application for license of major hydropower projects, including a discussion of the fish, wildlife, and botanical resources near the project. The discussion needs to identify the potential impacts of the project on these resources, including a description of any anticipated continuing impact for ongoing and future operations. SP-F10 Task 2B fulfills these requirements by evaluating the potential effects of the Oroville Facilities operations on spawning Chinook salmon in the lower Feather River.

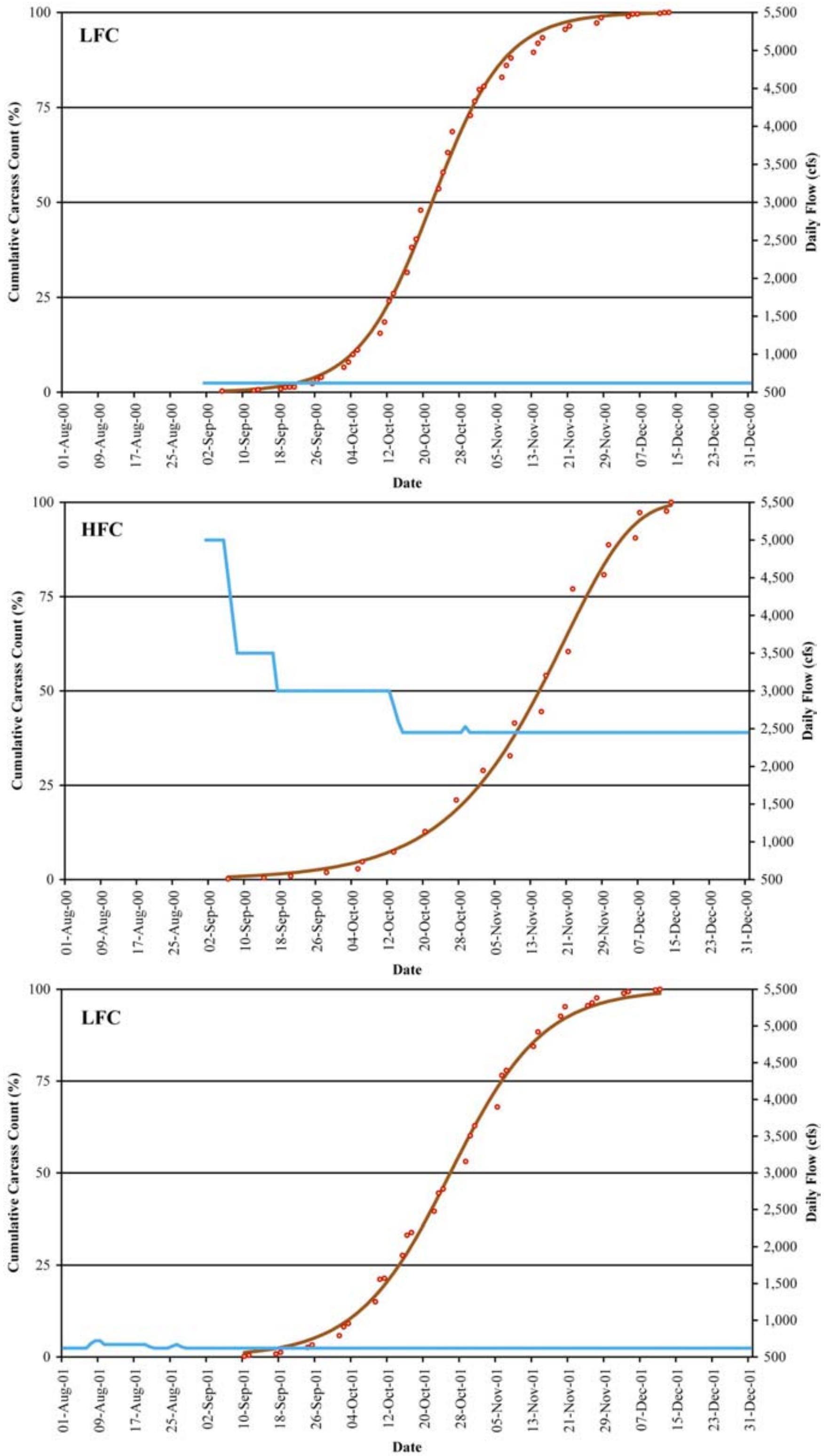


Figure 2.1-1. Average daily flows (cfs) (indicated by the blue line) and the corresponding observed cumulative carcass count percentages (circles), by survey day, during the spawning period for Chinook salmon in the lower Feather River, 2000, 2001, 2002, and 2003.

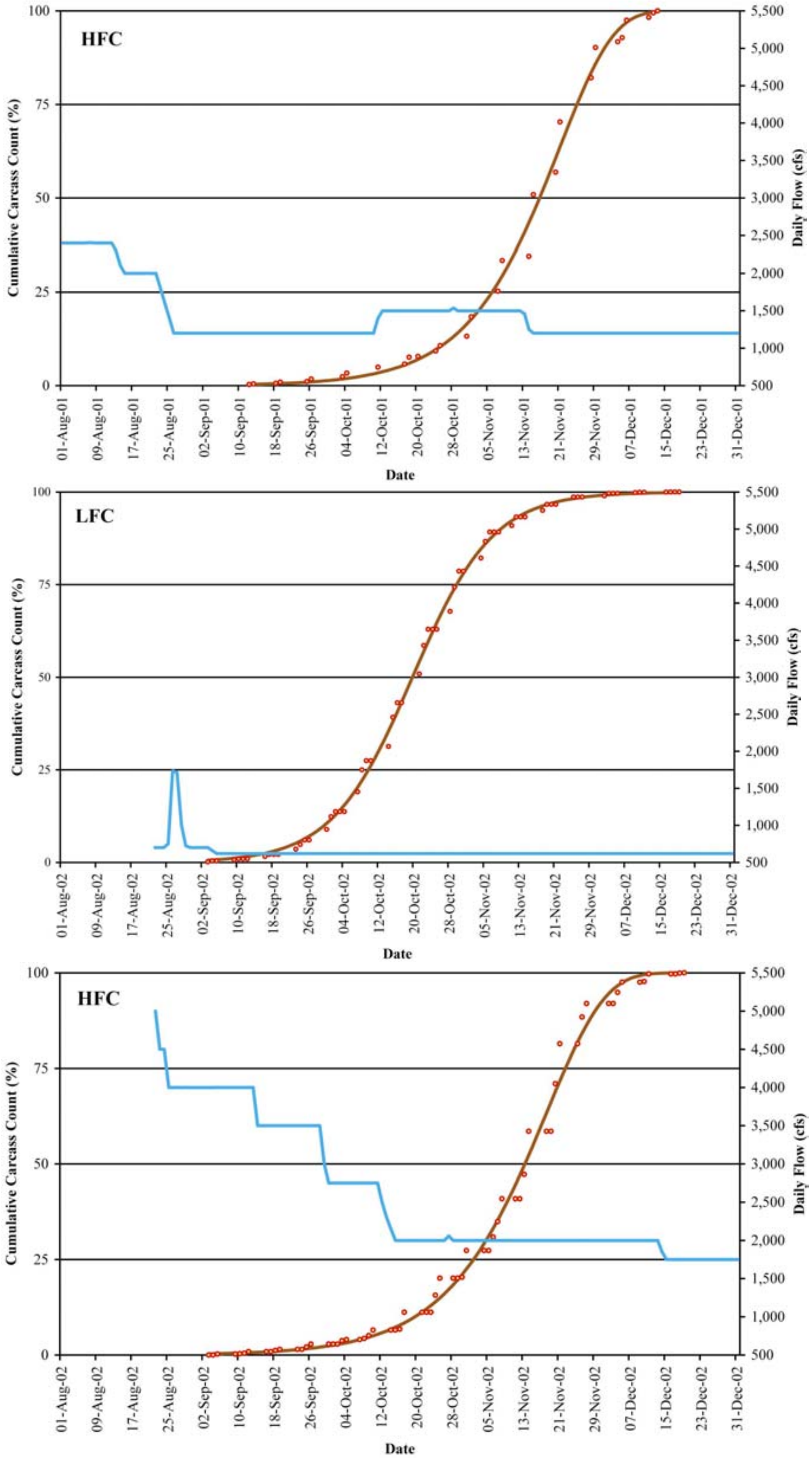
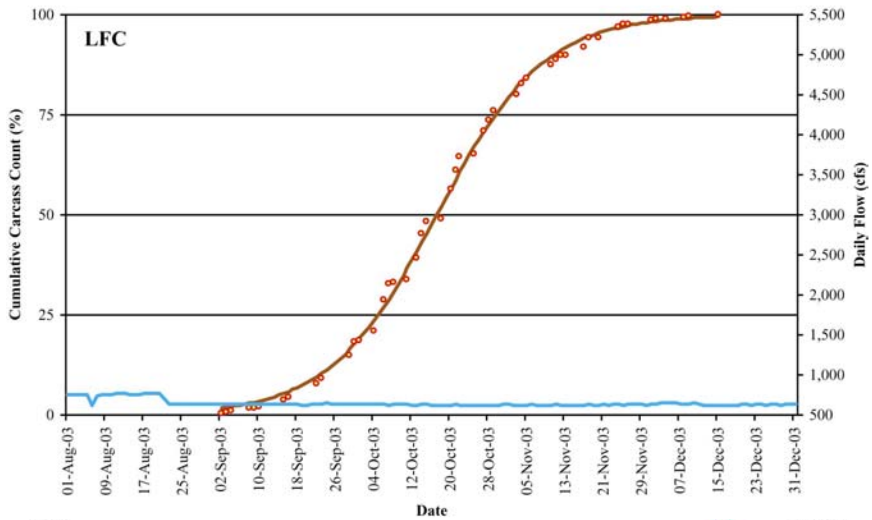


Figure 2.1-1 (Continued). Average daily flows (cfs) (indicated by the blue line) and the corresponding observed cumulative carcass count percentages (circles), by survey day, during the spawning period for Chinook salmon in the lower Feather River, 2000, 2001, 2002, and 2003.



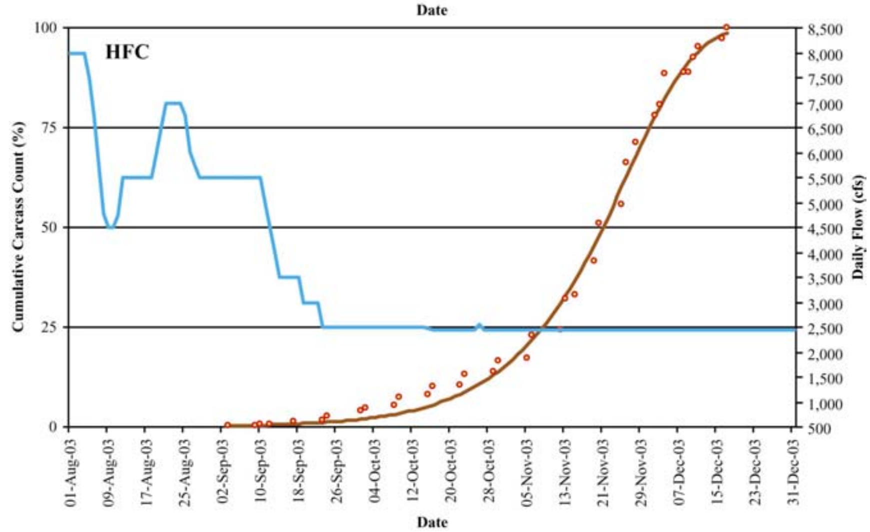


Figure 2.1-1 (Continued). Average daily flows (cfs) (indicated by the blue line) and the corresponding observed cumulative carcass count percentages (circles), by survey day, during the spawning period for Chinook salmon in the lower Feather River, 2000, 2001, 2002, and 2003.

2.1 SPAWNING STEELHEAD IN THE LOWER FEATHER RIVER

Language found in the Preliminary Draft Study Plan Package (DWR 2002c) for all objectives of SP-F10 Task 2B requires evaluations and assessments for each salmonid present in the lower Feather River, including steelhead. The Preliminary Draft Study Plan Package also specifies that SP-F10 Task 2B review and evaluate methods to measure steelhead spawning and perform redd surveys for steelhead. A decision was made by the Environmental Work Group (EWG) to address the spawning characteristics of steelhead as part of a separate task because of the sheer number of objectives already required under SP-F10 Task 2B. Two reports have been completed addressing the spawning characteristics of steelhead in the lower Feather River. An interim report was completed by DWR in May 2003 titled "*Interim Report SP-F10, Task 2B"* (DWR 2003b). The objective of that report was to conduct a literature review and evaluate opportunities for improvement in current methodologies used to quantify steelhead spawning in the lower Feather River. In July 2003, DWR completed a report titled "*SP*

F-10, Task 2B Report 2003 Lower Feather River Steelhead (Oncorhynchus Mykiss) Redd Survey" (DWR 2003a). The combined results from these two reports satisfy the requirements specified in SP-F10 Task 2B for addressing spawning steelhead. Therefore, steelhead will not be addressed in this report.

2.2 LIFE HISTORY OF CHINOOK SALMON

In California, Chinook salmon are found in larger lotic systems from the Oregon border south to the Sacramento-San Joaquin system. The Sacramento-San Joaquin system is the southernmost range for this species in the Pacific Northwest (Moyle 2002). DFG has planted Chinook salmon in several reservoirs in California, however natural reproduction in landlocked waterways has yet to be documented (Moyle 2002). The life history strategy of Chinook salmon is typically divided into two categories, stream-type and ocean-type. Across the range of Chinook salmon, there is variation within each of these broad categories that gives rise to stocks or runs. Spring-run Chinook salmon exhibit a stream-type life history. Adult spring-run Chinook salmon reportedly enter their natal tributaries as sexually immature fish and hold in the river over the summer while gonadal maturation takes place (DFG 1998a; DWR and USBR 2000; Moyle 2002). Historically, spring-run Chinook salmon were reported to have ascended to the very highest streams and headwaters in the lower Feather River watershed (DFG 1998a). The Fish Barrier Dam below Oroville Dam now restricts fish passage to historic spawning grounds at higher elevations (DFG 1998a). In the lower Feather River, it has been reported that adult spring-run Chinook salmon enter the river from March through June (Sommer et al. 2001), and spawn from August through October (DFG 1998a; DWR and USBR 2000; Moyle 2002). Currently, any Chinook salmon that spawns from mid-August through early October is considered spring-run by DFG (Nobriga and Buffaloe 2000). In recent years, all adults entering the FRFH between September 8 and October 1 have been classified as spring-run Chinook salmon (DFG 1998a). Juvenile stream-type salmon tend to rear in fresh water for longer periods of time (>1 year) prior to entering saltwater (Moyle 2002). Fall-run Chinook salmon, considered ocean-type, reportedly enter the lower Feather River in late summer and fall, and typically spawn shortly after arriving on the spawning grounds in late September through December (Sommer et al. 2001; Yoshiyama et al. 1998). Fall-run Chinook salmon stocks spawn in lowland reaches of larger rivers and tributaries. Juvenile ocean-type Chinook salmon tend to rear in fresh water for shorter periods of time (0-12 months) prior to entering saltwater (Moyle 2002). In the lower Feather River, however, it has been reported that both spring-run and fall-run juvenile Chinook salmon emigrate as fry shortly after emergence (DWR 2002a).

Upon reaching spawning areas, adult female Chinook salmon excavate shallow oval shaped depressions in appropriate gravel beds. The depressions, or nests, are known as redds. The general belief is that each female Chinook salmon constructs multiple redds, but observational data suggest one redd per female is most typical (Crisp and Carling 1989; Neilson and Banford 1983). Spawning occurs over several days, during which the female deposits up to five groups, or pockets, of eggs into the redd and then covers them with gravel (Healey 1991). After spawning, and prior to dying, female

Chinook salmon spend up to 25 days defending their redd (Healey 1991). The amount of time between egg fertilization and fry emergence varies temporally and spatially. After incubation, embryos hatch to live as alevin (sac-fry) within interstitial spaces of gravel substrates. The length of time alevins reside in gravel substrates varies, but usually lasts until the yolk sac is fully absorbed (Moyle 2002). Young Chinook salmon and steelhead are sometimes called fry upon emergence from gravel beds. During the transition from fry to parr, juvenile salmonids grow in size and spend more time utilizing deeper and higher velocity habitats for feeding and rearing (Moyle 2002). Juvenile Chinook salmon spend from several months to over a year rearing in freshwater prior to emigrating to saltwater. During emigration, the parr-smolt transformation takes place and involves morphological, physiological, and behavioral changes designed to increase saltwater survivability. In general, these changes occur gradually while juvenile salmonids are en-route from natal streams to the ocean. Chinook salmon spend between one to four years, but sometimes longer, in the ocean before returning to their natal streams to spawn (Myers et al. 1998).

2.3 GRILSE AND THEIR CONTRIBUTION TO THE SPAWNING CHINOOK SALMON POPULATION IN THE LOWER FEATHER RIVER

DWR conducted carcass surveys in the lower Feather River from the Fish Barrier Dam to the Gridley Bridge from September through December, 2000 through 2003. The collected data were used in the analyses contained in this report. Carcasses were classified as adult (male or female) or grilse. DWR defined grilse as any carcass measuring less than 26.8 in (68 cm) FL. Debate exists concerning the definition of grilse and their role in the spawning cycle. Most authors define a grilse as any salmon, usually a male, which has sexually matured after less than one year (Gross 1991; Moyle 2002). However, some authors consider 2 year old spawning salmon as grilse. Length frequency distributions are used to define the size criteria of grilse when age data from hard structures are unavailable. For example, in the lower American River, DFG defined male grilse as ≤ 27.6 in (70 cm) FL, and female grilse as ≤ 23.6 in (60 cm) FL (Snider and Vyverberg 1996). In the Trinity River, DFG defined spring-run Chinook salmon grilse as < 19.7 in (50 cm) FL, and fall-run Chinook salmon grilse as < 22.4 in (57 cm) FL (Zuspan et al. 1991). Grilse can be either male or female and are sometimes referred to as jacks and jills, respectively. Grilse also are known as precocious parr or precocious males. Grilse differ from adults morphologically, primarily in having a smaller body size, but are reproductively mature.

A literature review was conducted to determine the contribution of grilse to the spawning population and to determine the sex ratio of grilse within populations. Information of this type was used in estimating the size of the spawning population and the superimposition estimates for Chinook salmon in the lower Feather River. Much of the available literature concerning the life history of grilse has focused on males. In a laboratory study consisting of both grilse and adult Atlantic salmon, Garant et al. (2003) genetically analyzed 1,305 embryos for paternal strain and reported that 24.3 percent (375) were fertilized by precocious males. Garcia-Vazquez et al. (2001) studied Atlantic salmon in a natural setting enclosure to evaluate alternative male reproductive strategies. The results from this study concluded that morphologically juvenile, yet sexually mature males, fertilized a large percentage of eggs, and they thereby contributed to an increase of genetic variability in wild Atlantic salmon populations. Similar findings have been reported for coho salmon (Van Doornik et al. 2002). Garant et al. (2003) compared the reproductive success of male grilse and male adults through genetic analysis of offspring. The results from this study concluded that adult male Atlantic salmon had twice the reproductive success of grilse. In other words, grilse accounted for 33 percent of the reproductive success of that population. An important conclusion from this study was that the mean lengths of offspring of grilse were larger than the offspring of adults. Survivability of juvenile salmonids has been reported to be positively correlated with length (Ward and Slaney 1988; Wedemeyer et al. 1980). Thus, the offspring of grilse may have higher survival rates. Young (1999) demonstrated that the percentage of males spawning as precocious jacks can vary between populations of coho salmon at the basin-sub basin scale, and that a populations' jack percentages are related to environmental conditions experienced during different life history stages. Young (1999) also stated that patterns of interannual variation in the jack percentage appeared to vary, indicating that populations from different environments may have different demographic responses to similar climatic and marine conditions. The results from this study suggest the percentage of males spawning as precocious jacks is a synergistic function of multiple factors, and that the contribution from jacks to the spawning population within a population can vary from year to year. The role of male grilse in the spawning cycle has been well documented. However, there is a paucity of information concerning female grilse. Moyle (2002) stated that in certain years within the San Joaquin River system a significant percentage of the salmon runs are composed of two-year-old jacks (up to 67%) or jills (14% in 1996), although the source data for this information could not be located. Silverstein and Hershberger (1992) reported that in commercial aquaculture facilities where the life cycle of coho salmon is manipulated, nearly all precocious individuals are males.

The results from these studies indicate that, although variable, the overall contribution by male grilse to the total spawning population is large enough to be influential. The contribution to the spawning population by female grilse is unknown, as is the sex ratio of grilse populations. Some authors have reported an inverse relationship in the number of males exhibiting jack characteristics and an increase in latitude (Drucker 1972). Salmon are near their southern range extension in the Sacramento-San Joaquin system, so it is possible that this region has a disproportionately higher number of grilse. DWR conducted carcass surveys in the lower Feather River from 2000-2002 (unpublished data), and defined Chinook salmon grilse as any carcass measuring less than 26.8 in (68 cm) FL. During this study, spawned female salmon carcasses were found that met the length definition of grilse. Spent female carcasses measuring 22.4 in (57 cm), 16.5 in (42 cm), 20.5 in (52 cm), and 19.7 in (50 cm) were found in 2000, 2001, 2002, and 2003, respectively. Although the age of these carcasses was not confirmed, based on body length it seems reasonable to suspect that female Chinook salmon grilse spawn in the lower Feather River.

Therefore, for purposes of this report, Chinook salmon grilse, both male and female were included in the overall Chinook salmon spawning populations in the lower Feather River.

2.4 DIFFERENTIATING SPRING-RUN FROM FALL-RUN CHINOOK SALMON

Separating spawning spring-run Chinook salmon from spawning fall-run Chinook salmon has, historically, been based on time of spawning and differences in spawning site locations (Fry 1961). Spawning for each run, or race, typically occurs at specific times and in specific habitats, effectively maintaining temporal and spatial separation between races (Fisher 1994). Historically, reproductive isolation has been attributed to maintaining genetic integrity between spring-run and fall-run Chinook salmon in the Sacramento-San Joaquin system.

Construction of Oroville Dam eliminated access to high elevation headwater reaches of the Feather River that were the historic spawning grounds for spring-run Chinook salmon (Sommer et al. 2001). Restricted access to historic spawning grounds cause spring-run Chinook salmon to spawn in the same lowland reaches that fall-run Chinook salmon utilize as spawning habitat. The overlap in spawning sites, combined with a slight overlap in spawn timing (Moyle 2002) with temporally adjacent runs, may be responsible for in-breeding between spring-run and fall-run Chinook salmon in the lower Feather River (Hedgecock et al. 2001).

FRFH operations also may contribute to genetic introgression between spring-run and fall-run Chinook salmon in the lower Feather River. For example, repeatedly selecting early arriving fall-run Chinook salmon for brood fish could alter run timing, and inadvertently contribute to an overlap in spawning timing and genetic flow between races. A disproportionate number of earlier arriving salmon in the broodstock could potentially occur because hatcheries typically collect eggs until a certain quota is met. When large numbers of fish arrive at hatcheries early, quotas typically are met quickly and late arrivals may not be used as broodstock.

The temporal and spatial boundaries historically present between spring-run and fall-run Chinook salmon in the lower Feather River may be eroding, and some authors question whether the spring-run Chinook salmon in the Feather River are a genetically distinct run (Hedgecock et al. 2001; Sommer et al. 2001). Because run timing could potentially be different in the Feather River when compared to historic run timing, separating spawning spring-run from fall-run Chinook salmon based on a calendar day may be unreliable.

One method used to distinguish various Chinook salmon runs involves using standardized daily fork-length tables, or keys. Keys are developed for regional and site specific use. The Fisher Key (1994) and the Modified Fisher Key (1997; also known as the Delta Model Key) are commonly used by natural resource agencies in the Sacramento-San Joaquin system (pers. com., K. Souza, 2003). The methodology used to develop these keys is unavailable. Lengths of samples are compared, by sample date, to standardized tables in order to determine race. For example, on October 17 the Modified Fisher Key defines fall-run Chinook salmon as ranging from 4.8 in to 10.6 in (123-269 mm) FL and defines spring-run Chinook salmon as ranging from 10.6 in to 11.8 in (270-300 mm) FL. Keys are a useful tool for making general classifications but, when making resource management decisions, should be used with caution due to inherent uncertainties.

To determine if length frequency distributions could be used to separate spring-run from fall-run Chinook salmon in the lower Feather River, carcass survey data collected by DWR in 2002 were evaluated. Carcass data from the lower Feather River were grouped by sex, month, and reach (LFC and HFC). Single factor Analysis of Variance (ANOVA) and Tukey multiple comparison tests were used to evaluate differences among mean lengths (FL cm). Comparisons were made among sample months (September, October, and November-December), by reach, and sex. The carcass data for November and December were pooled because of small sample sizes in December. In the LFC, the mean lengths of female carcasses sampled in September were statistically different from the mean lengths of female carcasses sampled in October, and November-December (Table 2.4-1). However, in the HFC there were no statistically significant differences among sample months in the mean lengths of female carcasses sampled ($p=0.091$). In the LFC, there were no statistically significant differences among sample months in the mean lengths of male carcasses sampled ($p=0.058$; Table 2.4-2). In the HFC, the mean lengths of male carcasses sampled in October were statistically different from the mean lengths of male carcasses sampled in November-December. The results from this analysis precludes separation of spring-run and fall-run Chinook salmon using 2002 carcass survey data from the lower Feather River.

Based on a review of available methodologies, carcass survey data from the lower Feather River, and the sensitivities involved with the ESA listed spring-run Chinook salmon, the analyses in this report will not differentiate between spring-run and fall-run Chinook salmon.

Table 2.4-1. Results of single factor Analysis of Variance analyses (ANOVAs) and Tukey multiple comparison tests to compare the monthly mean lengths of female carcasses collected in the lower Feather River, 2002.

FEMALES in LFC

Groups	*Count*	*Sum*	*Average*	*Variance*
Sept	793	67,944	85.68	71.41
Oct	1,377	116,330	84.48	78.78
Nov + Dec	557	46,850	84.11	82.61

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Between Groups	1,012.41	2	506.21	6.538	0.001
Within Groups	210,895.48	2,724	77.42		
Total	211,907.90	2,726			

Tukey Multiple Comparison

m_1	m_2	$m_2 - m_1$	SE	*q*	$q_{0.05,2724,3}$	Conclude
Nov + Dec	Oct	0.369	0.312	1.182	2.345	$m_1 = m_2$
Nov + Dec	Sept	1.568	0.344	4.56	2.345	$m_1 \neq m_2$
Oct	Sept	1.199	0.277	4.323	2.345	$m_1 \neq m_2$

FEMALES in HFC

Groups	*Count*	*Sum*	*Average*	*Variance*
Sept	76	6,624	87.16	54.27
Oct	284	24,969	87.92	75.71
Nov + Dec	437	37,792	86.48	76.62

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Between Groups	357.02	2	178.51	2.406	0.091
Within Groups	58,902.33	794	74.18		
Total	59,259.35	796			

Table 2.4-2. Results of single factor Analysis of Variance analyses (ANOVAs) and Tukey multiple comparison tests to compare the monthly mean lengths of male carcasses collected in the lower Feather River during the 2002 carcass survey.

MALES in LFC

Groups	*Count*	*Sum*	*Average*	*Variance*
Sept	438	39,679	90.59	239.22
Oct	916	81,771	89.27	278.68
Nov + Dec	316	28,977	91.7	290.59

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Between Groups	1,544.66	2	772.33	2.854	0.058
Within Groups	451,068.68	1,667	270.59		
Total	452,613.34	1,669			

MALES in HFC

Groups	*Count*	*Sum*	*Average*	*Variance*
Sept	42	3,822	91	205.8
Oct	267	24,171	90.53	312.17
Nov + Dec	321	27,641	86.11	360.86

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Between Groups	3,172.54	2	1,586.27	4.806	0.008
Within Groups	206,951.72	627	330.07		
Total	210,124.26	629			

Tukey Multiple Comparison

m_1	m_2	$m_2 - m_1$	SE	*q*	$q_{0.05,627,3}$	Conclude
Nov + Dec	Oct	4.419	1.064	4.153	2.349	$m_1 \neq m_2$
Nov + Dec	Sept	4.891	2.108	2.32	2.349	$m_1 = m_2$
Oct	Sept	0.472	2.132	0.221	2.349	$m_1 = m_2$

2.5 DISCRIMINATING HATCHERY CHINOOK SALMON FROM WILD CHINOOK SALMON

Increased mitigation requirements due to loss of Chinook salmon habitat from disturbance activities have increased the influence and significance of hatchery operations with regard to the stability of Pacific Northwest salmonid stocks. Discrimination between hatchery and wild stocks is necessary to monitor the status of stocks, and to assess the success of hatchery mitigation programs (Hankin 1982). Many techniques are used to mark or tag hatchery reared salmon and steelhead, but the CWT system is probably the most frequently used. The CWT (coded wire tag) is a small piece of magnetized stainless steel wire (usually 1.1 mm long x 0.25 mm in diameter) containing unique coding allowing identification of individuals, brood year, and hatchery of origin (Guy et al. 1996). CWTs are subcutaneous tags typically inserted in the forward portion of the head or snout of salmonids using a syringe.

Advantages of using CWTs include the ability to tag very small fish, minimal damage to tissues in the tagging process, and cost effectiveness. Tag recovery is dependent on the ability of field personnel to recognize tagged fish. The process is facilitated by externally marking individuals containing a CWT, usually by removing the adipose fin. In the lower Feather River, recovery is dependent on recognizing carcasses with a clipped adipose fin. The type of information gained from CWT programs include discrimination between strains and runs, age at return estimates, the temporal and spatial distribution of spawning hatchery fish, escapement estimates, and straying rates. Estimates based on CWT data should be viewed cautiously because tags can be shed, personnel may not detect all fish that contain tags, clipped fins can regenerate, and not all hatchery fish are tagged and marked. Therefore, estimates may not be reflective of true population parameters. In addition, because not all hatchery fish are marked and tagged, fish lacking an adipose fin clip cannot safely be identified as originating from naturally spawning parents, and thus cannot be necessarily considered wild.

2.6 ANNUAL VARIATION IN THE CHINOOK SALMON SPAWNING POPULATION IN THE LOWER FEATHER RIVER

Escapement estimates for Chinook salmon in the lower Feather River are available from 1953 through 1994. Fry (1961) reported the escapement for both spring-run and fall-run Chinook salmon from 1953 through 1959. The estimates reported were calculated from spawning ground surveys conducted by DFG. The 1958 and 1959 estimates were supplemented with aerial redd counts. Painter et al. (1977) conducted carcass surveys in the lower Feather River from 1968 through 1974, and estimated Chinook salmon spawning populations by counting carcasses, then expanding counts by an estimate of survey efficiency. The survey efficiency was determined through a carcass mark-recapture design, and comparing estimates to weir count totals tested the accuracy of the spawning population estimate. Painter et al. (1977) also provided escapement estimates from 1960 through 1967, citing Menchen (1970) as the source of the information. However, the data and methodology supporting these estimates could not be located. Sommer et al. (2001) summarized available literature and provided spawning escapement estimates of spring-run and fall-run Chinook salmon from 1953 through 1994 in the lower Feather River. The estimates were based on several studies, each with different methodologies, and provided a general trend of escapement, which should be interpreted cautiously.

Historic spawning escapement estimates for fall-run Chinook salmon in the lower Feather River are shown in Figure 2.6-1. The FRFH was opened in 1967 to compensate for the loss of upstream habitat by the construction of Oroville Dam. The facility is operated by DFG, and typically spawns approximately 10,000 adult Chinook salmon each year. Escapement estimates for fall-run Chinook salmon prior to the construction of the Oroville Dam were variable, and ranged from a low estimate of approximately 10,000 in 1957 to a high estimate of approximately 86,000 in 1955 (Fry 1961; Painter et al. 1977). More recent escapement estimates still show variability, but appear to be more stable than before Oroville Dam was constructed (Painter et al. 1977; Sommer et al. 2001). Escapement estimates after dam construction ranged from a low estimate of approximately 18,000 in 1968 to a high estimate of approximately 74,000 in 1973. Pre-dam annual escapement estimates averaged approximately 41,000 Chinook salmon compared to approximately 46,000 thereafter.

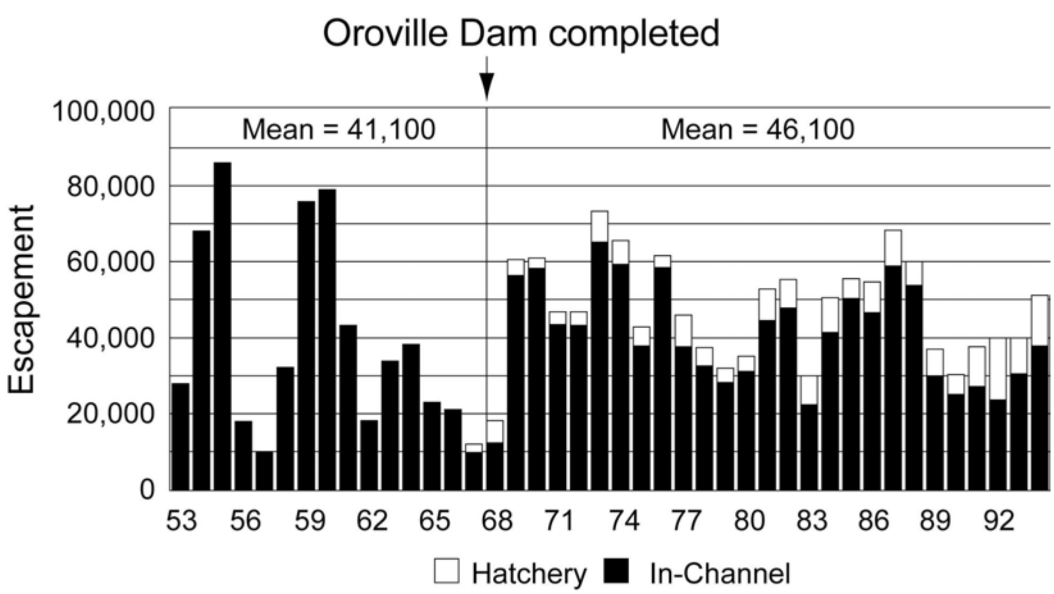


Figure 2.6-1. Escapement of fall-run Chinook salmon (1953-1994) from the Feather River Fish Hatchery and main river channel (Sommer et al. 2001).

The historic spawning escapement estimates for spring-run Chinook salmon in the lower Feather River are shown in Figure 2.6-2 (Sommer et al. 2001). According to Painter and Wixom (1975), an objective of the FRFH is to maintain spring-run Chinook salmon population levels at least as high as pre-dam levels, which is assumed to be 2,000 adults. Escapement estimates for spring-run Chinook salmon prior to the construction of the Oroville Dam ranged from a low of approximately 300 individuals in 1966 to a high of approximately 4,000 individuals in 1960 (Fry 1961; Painter et al. 1977). Escapement estimates after dam construction ranged from a low of approximately 400 individuals in 1970 to a high of approximately 6,800 individuals in 1988. Pre-dam annual escapement estimates averaged approximately 1,718 spring-run Chinook salmon compared to approximately 1,634 thereafter. The FRFH reportedly is currently the only source of spring-run Chinook salmon eggs in the Sacramento-San Joaquin system, and could play a key role in the restoration of the race (Reynolds et al. 1993). However, it should be noted that the genetic identity of the spring-run Chinook salmon in the lower Feather River is questionable (Sommer et al. 2001).

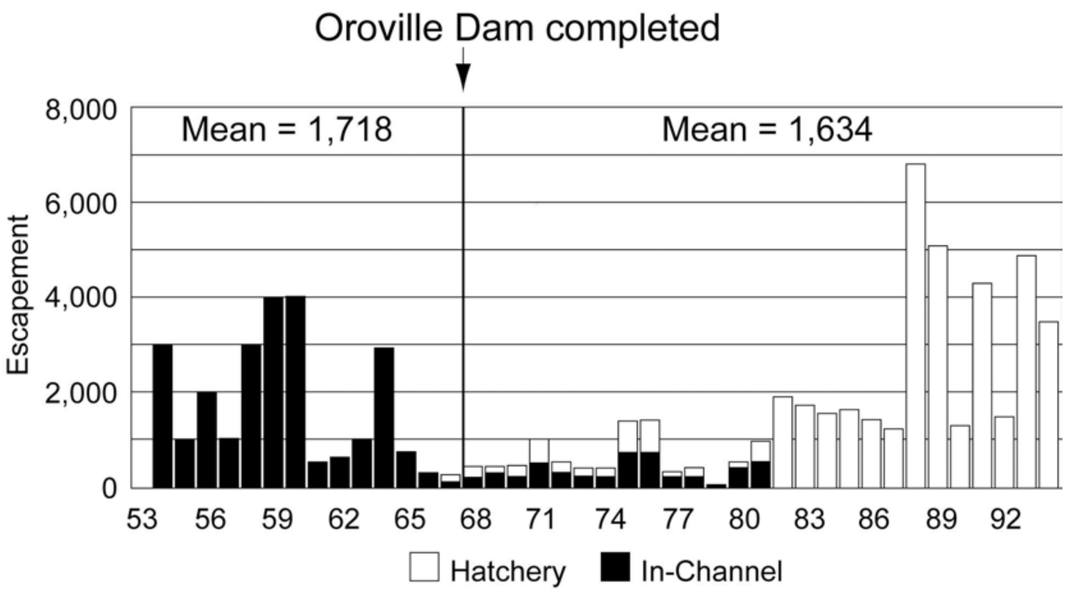


Figure 2.6-2. Escapement of spring-run Chinook salmon (1953-1994) from the Feather River Fish Hatchery and main river channel (Sommer et al. 2001).

2.7 WATER TEMPERATURE TOLERANCE VALUES FOR THE SPAWNING AND EGG INCUBATION LIFE STAGE OF CHINOOK SALMON

In the past century, anadromous salmonid populations in the Central Valley of California have experienced reductions in size and range, in some cases to extinction (Myrick and Cech 2001). Water diversions, particularly the construction of major dams, are often reported as a major cause of decline. The construction of dams could potentially impact salmonid populations by blocking passage to traditional spawning and rearing habitat, changing natural flow regimes, and changing temporal and spatial water temperature regimes. Because Chinook salmon are poikilothermic, water temperature is an important physical habitat parameter for all life stages. Many of the mainstem rivers and tributaries in the Sacramento-San Joaquin system contain impoundments and diversions that are regulated by agencies such as SWRCB, DFG, USFWS, and NOAA Fisheries. Typically, water diversion and water use projects affect in-river water temperatures by altering flow regimes. Regulatory requirements mandate provision of various water temperature ranges to accommodate each salmonid life stage. Development and appropriate application of technical evaluation guidelines is necessary when assessing the suitability of water temperatures for Chinook salmon. In general, differences exist between the thermal requirements of each life stage of Chinook salmon. Therefore, salmonid life stages should be explicitly defined prior to selecting the appropriate water temperature index values to be used as guidelines for impacts assessment.

The in-river portion of the life cycle of adult Chinook salmon consists of multiple stages including adult migration and holding, spawning site selection, redd construction, egg and alevin incubation, and residence time on redds. Response to, and the effects from, water temperature during each life stage vary. In general, spawning and embryo incubation are evaluated together because it is difficult to definitively separate these two stages. In this report, the spawning and embryo incubation life stage is defined as the period from redd construction through alevin emergence. This report will focus on the effects of water temperatures on adult Chinook salmon while on the spawning grounds. The effects to incubating eggs and alevins are specifically addressed in SP-F10 Task 2C "*Evaluate the timing, magnitude and frequency of water temperatures and their effects on the distribution of salmonid spawning and on egg and alevin survival.*"

A review of available literature was conducted to determine appropriate water temperature index values for spawning Chinook salmon. Many of the water temperature values mentioned in the available literature are supported by anecdotal evidence, and values derived from experimental testing are limited. In general, three types of literature provide information on criteria used for resource management decisions: research results that are typically published in peer reviewed journals; literature reviews citing various types of documents; and, agency publications that often contain legal mandates. Many of the water temperature index values currently used as technical evaluation guidelines to assess impacts to Chinook salmon were established decades ago through controlled experiments and observations. Chambers (1956) described spawning site characteristics for 27 streams in Washington, Idaho, and Oregon. Spring-run Chinook salmon were observed spawning at water temperatures between 40°F (4.4°C) and 55°F (12.8°C) with an average daily water temperature of 54°F (12.2°C). Fall-run Chinook salmon were observed spawning at water temperatures between 41°F (5°C) and 56°F (13.3°C) with an average daily water temperature of 50°F (10°C). Chambers (1956) also reported that declining water temperatures appeared to act as a cue initiating the spawning cycle. Seymour (1956) reported that the shortest hatching period occurred in egg lots reared in the water temperature range of 40 to 58° F (4.4-14.4°C), and that short hatching periods are associated with high survival. Other relevant conclusions from this study were that 100 percent mortality occurred during the yolk-sac stage in egg lots reared at 60°F (15.6°C) and 62.5°F (16.9°C), and the mortality rate was low at all stages of development for lots reared at water temperatures between 40 to 55°F (4.4-12.8°C). In an annual report concerning the productivity of the Nimbus Fish Hatchery on the American River, Hinze (1959) reported basic observations on the correlation between water temperature and incubating eggs. The report states there was 100 percent mortality of eggs taken and incubated in water above 62°F (16.7°C), a yield of 50 percent to the eyed stage when eggs were taken and incubated in water between 60 to 62° F (15.6-16.7°C), and a yield of 80 percent to the eyed stage when eggs were taken and incubated in water between 55 to 59° F (12.8-15°C). Combs and Burrows (1957) tested the effect of constant incubation water temperatures on the development of Chinook salmon eggs. The study concluded that water temperatures between 42.5°F (5.8°C) and 57.5°F (14.2°C) provided for normal development, but those results applied only to eggs incubated at constant water temperatures. Dauble and Watson (1997) monitored spawning Chinook salmon in the Hanford Reach of the mid-Columbia River from 1948 through 1992. During the monitoring period, fall-run Chinook salmon spawned at mean daily water temperatures ranging from 53.6°F (12°C) to 65.3°F (18.5°C). Mean weekly water temperature at first observed spawning was 59.5°F (15.3°C) from 1948 to 1988. Approximately 75 percent of the spawning was initiated when weekly mean water temperatures dropped to 57.2 to 60.8°F (14-16°C). During peak spawning, the mean weekly water temperature was 54.5°F (12.5°C) and the maximum weekly water temperature was 57.2°F (14°C). Groves and Chandler (1999) described spawning habitat used by fall-run Chinook salmon in the Snake River. The overall distribution of mean weekly water temperatures obtained from 151 redds from 1993 to 1995 ranged from 41 to 60.6°F (5-15.9°C), and averaged 50.9°F (10.5°C). Water temperatures averaged 56.5°F (13.6°C) during the week when spawning was initiated, and 45.5°F (7.5°C) during the week that spawning activities concluded.

Many literature reviews have summarized the thermal tolerances of the spawning and embryo incubation life stage of Chinook salmon, and many of these reviews are commonly cited in the literature. Chinook salmon reportedly have been observed spawning throughout a wide range of temperatures (39.9 to 64.4°F; (Raleigh et al. 1986), due, in part, to variation in climatic conditions across their geographical range. A literature review by Bjornn and Reiser (1991) concluded that, based on Bell (1986), water temperatures between 42.1°F (5.6°C) and 57°F (13.9°C) are recommended for the spawning and incubation life stage of Chinook salmon. Bell (1991) reviewed available literature and determined that the general water temperature range appropriate for spawning Chinook salmon was between 42°F (5.6°C) and 57.5°F (14.2°C), with 51.8°F (11°C) reported as the preferred water temperature for spawning, although the values listed in Bell (1991) include a typographical error (pg. 11.3), which was also present in Bell (1986) (pg. 95); also it is difficult to determine the source data the water temperature values were based on. Boles (1988) relied heavily on the results from Seymour (1956) to conclude that eggs incubated at constant water temperatures greater than 60° F (15.6°C) suffer high mortalities. McCullough (1999) concluded that 42 to 55°F (5.6-12.8°C) appeared to be a reasonable recommendation for a water temperature range for spawning Chinook salmon in the Columbia River Basin. McCullough (1999) recommended this range of values because alevin development (which is linked to thermal exposure of eggs in ripe females, or newly deposited in gravels) and egg maturation are negatively affected by exposure to water temperatures above approximately 54.5 to 57.2°F (12.5-14°C). The literature review also stated that it could be assumed that spawning will not occur at water temperatures greater than approximately 60.8°F (16°C).

Documents from regulatory agencies, such as biological opinions and biological assessments, offer additional literature from which water temperature values can be derived. Maximum water temperatures of 55°F (12.8°C) have typically been recommended for Chinook salmon spawning because studies of egg survival and development indicate reduced survival under water temperatures between 53.6 to 60.8°F (12-16°C) (EPA et al. 1971). In the Sacramento River from Keswick Dam to Bend Bridge, NOAA Fisheries (1993) determined that during October a water temperature of 60°F (15.6°C) was appropriate for protecting late incubating larvae and newly emerged fry, and that the optimum water temperature for egg development was between 43 to 56°F (6.1-13.3°C). NOAA Fisheries (1997) reported that the preferred water temperature for Chinook salmon incubation generally is 52°F (11.1°C) with lower and upper threshold water temperatures of 42 to 56°F (5.6-13.3°C), and that reduced egg viability and significant egg mortality occurs at water temperatures in excess of 57.5°F (14.2°C). NOAA Fisheries (2002) somewhat agreed with these values, reporting that the range of suitable water temperatures for incubation and emergence is 48 to 52°F (8.9-11.1°C), and that the upper limit of water temperatures suitable for spawning is 56°F (13.3°C). Additionally, NOAA Fisheries (2002) reported the preferred water temperatures for eggs and fry is 53 to 58° F (11.7-14.4°C). USFWS (1995) determined that maximum survival of eggs and yolk-sac larvae occurs at water temperatures between 41 to 56°F (5-13.3°C), and that mature female Chinook salmon subjected to prolonged exposure to water temperatures above 60°F (15.6°C) have poor survival rates and produce less viable eggs than females exposed to lower water temperatures. USFWS (1999) studied the effect of water temperature on early-life survival of Sacramento River Chinook salmon and concluded that incubation water temperatures above 56°F (13.3°C) result in significantly higher alevin mortality, and that incubation water temperatures of 62 to 64°F (16.7-17.8°C) appeared to be the physiological limit for embryo development resulting in 80 to 100 percent mortality prior to emergence. The Oregon Department of Environmental Quality (Technical Advisory Committee et al. 1995) conducted a literature review and recommended a spawning water temperature range of 42 to 55°F (5.6-12.8°C) for Chinook salmon because the exposure of newly deposited eggs to water temperatures above approximately 55°F (12.8°C) increases egg mortality, and inhibits subsequent alevin development. A summary of technical literature by the Environmental Protection Agency (2001a) concluded that a suitable water temperature range of 42 to 55°F (5.6-12.8°C) appeared to be a reasonable recommendation for spawning Pacific salmon. In a separate report, the EPA (EPA 2001) quoted the Independent Scientific Group (1996) as stating that the optimal temperature for anadromous salmonid spawning is 50°F (10°C), and that stressful conditions for anadromous salmonids begin at a water temperature of 60.1°F (15.6°C) with lethal effects occurring at 69.8°F (21°C). The "*EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards*" (Palmer 2003) discusses criteria and describes an approach that EPA Region 10 encourages states and authorized tribes in the Pacific Northwest to use when adopting temperature water quality standards to protect coldwater salmonids. The criteria were developed by a multi-agency panel through a review and summary of the latest literature related to water temperature and salmonids. Based on the criteria in this publication, the EPA suggests that the seven-day average of the daily maximum water temperatures should not exceed 55.4°F (13°C) during the period when Chinook salmon are spawning and eggs are incubating.

In general, the process of establishing water temperature impact assessment criteria involves subjectivity. The use of models may limit subjectivity by standardizing the decision making process. The salmon mortality model, developed by the U. S. Bureau of Reclamation (2004), is a tool frequently used to predict early life stage salmon mortality, based on many variables, in rivers in the Central Valley including the Feather and American Rivers. The model specifies that water temperatures less than 56°F (13.3°C) result in a natural rate of mortality for fertilized Chinook salmon eggs, 100 percent mortality of fertilized eggs occurs after 12 days at 62°F (16.7°C), 100 percent mortality of fertilized eggs occurs after 7 days at 64°F (17.8°C), and 100 percent mortality of alevins occurs after 10 days at 64°F (17.8°C).

The lower Feather River is near the southern extent of the geographic range of Chinook salmon. Water temperatures during the Chinook salmon spawning season in the lower Feather River may be near the upper range of reported thermal tolerances. Temperatures in the Central Valley remain relatively mild throughout the year, and therefore the effects of elevated water temperatures are the primary concern. Water temperatures in the lower Feather River rarely drop below 45°F (7.2°C; see interim report SP-F10 Task 4B). Based on the literature review provided above, 45°F likely would not result in adverse effects to the spawning and embryo incubation life stage. Therefore, this report will only address the effects on the spawning and embryo incubation life stage of Chinook salmon from elevated water temperatures, and will not evaluate effects of low water temperatures.

Selection of water temperature index values for use as impact assessment criteria for the spawning and embryo incubation life stage of Chinook salmon is difficult because of the wide range of values, often contradictory, recommended in available literature. The water temperature index values selected for use in this report (see section 5.1) were chosen from values reported and recommended in regulatory agency documents and from source data, usually peer reviewed journal articles. Values found in the documents of regulatory agencies are important because they have legal ramifications, and water use projects typically are mandated to operate within the thermal criteria set forth in these documents.

Water temperature values reported for the spawning and embryo incubation life stage of Chinook salmon, in many instances, are the results of direct observations of spawning fish. The reported values do not necessarily reflect preferred or optimal water temperatures, but simply those water temperatures at which salmon were observed spawning. Conditions responsible for maximizing the number of adults spawning, the number of eggs deposited, and the number of eggs and alevins surviving is likely a complex synergistic interaction of multiple variables. The specialized life history of salmon restricts flexibility in the duration and timing of the spawning cycle. Spawning salmon are temporally constrained, and regardless of whether conditions are conducive to spawning, they eventually will spawn or die. For example, during unseasonably warm years, salmon may spawn well outside reported preferred, optimal, or suitable water temperature ranges. Therefore, caution should be used in the interpretation and application of water temperature index values derived from observations of spawning Chinook salmon.

2.8 SPAWNING TIMING OF CHINOOK SALMON IN THE LOWER FEATHER RIVER

Determining the spawning time frame for Chinook salmon in the lower Feather River was necessary in order to accomplish the objectives of SP-F10 Task 2B. A rough estimate was determined by using the dates of carcass detection from the carcass survey conducted by DWR. Carcass detection dates only reveal when carcasses were discovered, and do not account for the time that elapsed between the initiation of spawning activity and discovery of carcasses. To adjust for this lag in time so that spawning time frame estimates are closer to true values, a literature review was conducted. Neilson and Banford (1983) reported that Chinook salmon in the Nechako River in British Columbia resided on redds from 6 to 25 days with a mean of 14.5 days for one study reach, and 15.4 days for another study reach. Similar results were reported from the Kenai River in Alaska where Burger et al. (1985) utilized radio telemetry to characterize the timing and duration of spawning of two runs of Chinook salmon. Burger et al. (1985) reported that early run and late run Chinook salmon resided at spawning areas an average of 13 days and 18.4 days, respectively. Chinook salmon in the Morice River in British Columbia reportedly defended redds from 4 to 18 days with mean residence times of 7.7 days for late arriving spawners, and 13.1 days for early arriving spawners (Neilson and Geen 1981). Both the Morice and Nechako River populations were mainly stream-type Chinook salmon, although scale analysis indicated the presence of ocean-type Chinook salmon as well. Allen and Hassler (1986) *in* Vronskiy (1972) reported that each Chinook salmon spawns over a period of 5 to 14 days and may defend the nest from 5 to 9 days after spawning. The results from this study infer a redd residence time of between 10 and 23 days. SWRI (2003) estimated the time between redd construction and carcass detection in the lower American River from 1992 through 1995. Earlier in the spawning season, the number of days separating these events varied from a low of 16.2 days to a high of 19.9 days with a mean of 17.6 days. Later in the spawning season, the number of days separating redd construction and carcass detection was between 19.9 to 24 days with a mean of 21.3 days.

The study conducted by SWRI (2003) is of particular importance because of the proximity of the American River to the Feather River, and because they addressed time to carcass detection, not just redd residence time. Based on this study, a three-week adjustment was used to offset the lag in time between redd construction and carcass detection. Three weeks represents the upper mean of this study. Combining all carcass survey years, surveys were conducted in the lower Feather River from September 2 through December 19. To determine the approximate spawning time frame, the three-week adjustment will be applied at the beginning of the carcass detection period. The end of the spawning period will be consistent with the end of the carcass survey because carcasses were still being discovered as of the end date.

2.9 SPAWNING HABITAT

Suitable spawning habitat varies for each life stage associated with spawning, and site selection is likely an intrinsic function involving multiple life stage requirements. Suitable spawning habitat for successful redd construction is typically associated with gravel size. Female Chinook salmon must be able to move gravels to excavate redds in the streambed. Available gravel size may limit successful spawning by salmon through physical limitations. The ability of salmon to physically move gravels can be of particular concern in systems where dams prevent or limit recruitment of smaller, mobile gravels, leaving only bed material too large to be moved (Parfitt and Buer 1980 *in* Kondolf 2000). The process by which this occurs is known as armoring. The largest spawning individuals set the upper size limit of suitable gravel size because larger fish can move larger gravels. Kondolf (2000) suggested that spawning fish could move gravels with a median diameter up to approximately 10 percent of their body length. For successful egg incubation, gravels must be sufficiently free of fine sediments so that the flow of water through the gravel brings adequate dissolved oxygen levels to the eggs, and removes metabolic wastes. Some authors suggest that site selection is, in part, a function of upwelling and downwelling water flows, presumably because these areas may provide higher dissolved oxygen levels and better flushing qualities. Water temperature also is a descriptor of salmon spawning habitat because it influences the amount of dissolved oxygen that water contains. When gravels contain high levels of fine sediment, typical of drainages sustaining high levels of disturbance activities, the permeability of gravels is lowered, resulting in decreased intragravel dissolved oxygen concentrations and decreased egg survival (see discussions in (Groot and Margolis 1991). Studies relating gravel permeability to egg survival indicate that appropriate dissolved oxygen concentrations for incubating eggs vary, but reported minimums generally fall between 2 and 8 mg/L (Kondolf 2000; Silver et al. 1963). The lower limit of suitable spawning gravel size is defined by the amount of intragravel sediment present (Kondolf 2000). Apart from limiting DO and waste metabolite removal, fine sediments also can block the passage of emerging alevins. Emergence requires that hatched alevins living in intragravel spaces pass freely through connected pore space. Therefore, areas where the intergravel matrix is congested with fine sediment offer low quality spawning habitat.

Describing suitable spawning habitat is not a simple process because many factors contribute to the quality of spawning habitat. Appropriate spawning habitat probably is best defined by a combination of variables including gravel size, dissolved oxygen concentration, permeability, intragravel flow characteristics, and water temperature.

2.10 INSTREAM FLOW AND SPAWNING HABITAT AVAILABILITY

The Instream Flow Incremental Methodology (IFIM) is a tool used by resource managers to assess the effects of flow manipulation on riverine habitats. DWR (Cavallo 2002) stated that IFIM is the most widely used and defensible technique for assessing instream flow requirements of fish. IFIM includes a wide variety of methods of varying complexity, including sophisticated models such as Physical Habitat Simulation

(PHABSIM). PHABSIM is described as having been developed to calculate the quantity and usage of physical habitat within a stream or river system given the channel structure, flow, and aquatic species criteria. The PHABSIM model uses physical habitat measurements to predict, among other variables, the amount of useable spawning habitat at various river flows. PHABSIM uses either one-dimensional transect cross-sections or two-dimensional reach hydraulic models to simulate depths and velocities over a range of flows, then links these values with habitat suitability criteria to relate the match between flow and physical habitat. The PHABSIM model calculates a statistic called WUA (Weighted Usable Area), which represents the available habitat for various species and life stages. The WUA index is calculated using water depth, velocity, channel substrate, and sometimes cover data, and is usually expressed in units of square feet per 1,000 linear feet. Each transect used for data collection is weighted based on habitat preference suitability curves (for the species of concern), and then multiplied by a length of watercourse to produce an area. WUA is calculated at various flow regimes, and curves are produced predicting incremental changes in useable habitat with changes in flow (Williams 1996). In general, PHABSIM tends to work well when a species or life stage is capable of physically utilizing the entirety of a river channel and to actively seek areas most suitable to its life history needs (DWR 2002b). Good results can be expected for strong swimming adult fish or for spawning activity that correlates well to specific combinations of velocity, depth, and substrate. Less reliable results can be expected for weak swimmers that can barely hold position (pelagic fry), for those species that utilize micro-habitat niches poorly sampled by hydraulic measurements (i.e., amphibian egg masses behind rocks), for schooling species whose behavior is driven more by association with others and less by physical habitat variables, or for those species with poorly studied behavioral traits (i.e., territorial loyalty). Used appropriately, IFIM, PHABSIM, and WUA can be a useful decision-support system designed to help natural resource managers and their constituencies determine the benefits or consequences of different water management alternatives (Bovee et al. 1998).

2.11 PRE-SPAWN MORTALITY

For purposes of this report, pre-spawn mortality is defined as the proportion of females in the spawning escapement that dies prior to spawning. Typically, pre-spawn mortality estimates are based on carcass survey data relying on direct observation of carcass ovaries. The factors responsible for pre-spawn mortality are poorly understood, although water temperature and disease appear to be significant contributors (Healey 1991; McCullough 1999). Isolating the degree of influence that water temperature and disease have on pre-spawn mortality rates is difficult because water temperature and disease are likely only contributing factors. For example, spatial and temporal variation in ocean conditions can strongly influence the physical condition of migrating salmonids. Migrating salmon in poor condition are affected to a higher degree when exposed to stressful conditions, and are more likely to die prior to spawning. Salmon in poor condition also are more susceptible to disease. Salmon that die unspawned represent an important loss to egg production, and potential decreased escapement in subsequent years. Pre-spawn mortality rates are usually low, but can vary across regions and through time. Shepard (1975) *in* Healey (1991) reported a 19.1 percent pre-spawn mortality estimate for Bear River Chinook salmon, and that 30 of 230 female Chinook salmon in the Babine River died unspawned. In 1965, approximately 25 percent of Chinook salmon in a spawning channel at Priest Rapids, Washington, died prior to spawning, reportedly due to a protozoan infection of the gills (Pauley 1965, as cited *in* Healey 1991). In 1988, DFG reported that in the Trinity River, pre-spawn mortality ranged from a high of 75 percent at the beginning of the spawning season, to a low of 23 percent in the final weeks (Zuspan et al. 1991). The overall female Chinook salmon pre-spawning mortality rate during the survey period was 44.9 percent. The percentage of females that died prior to spawning in the American River ranged from 3 percent in 1993 to 19 percent in 1995 (Williams 2001).

2.12 REDD SUPERIMPOSITION

Redd superimposition occurs when spawning Chinook salmon dig redds on top of the redds of other Chinook salmon. The rate of superimposition is a function of spawning densities and flow, and typically occurs in systems where spawning habitat is limited (Fukushima et al. 1998). Superimposition of redds may result in poor egg to fry survival rates due to disruption of previously constructed redds (Litchfield and Willete 2002). Redd disruption can result in increased egg and alevin mortality leading to reduced production. Redd superimposition may disproportionately affect early spawners, and therefore potentially impact Chinook salmon exhibiting spring-run life history characteristics. Previous field observations suggest high rates of superimposition in the lower Feather River, particularly in the LFC (Sommer et al. 2001).

Many factors influence superimposition rates including flow and water temperature, spawning escapement densities, proportion of females in the population, habitat availability, redd characteristics, and egg incubation timing. The duration of egg incubation could be particularly influential. For example, if Chinook salmon exhibiting spring-run life history characteristics spawn over a month prior to the overall peak spawning period, and eggs hatch after a few weeks, the impacts of superimposition on the early spawners could be low. The amount of time between fertilization and emergence varies temporally and spatially but has been reported to be primarily a function of water temperature, with a negative correlation between duration and water temperature (Seymour 1956; Technical Advisory Committee et al. 1995). Typically, the accumulated thermal unit index (ATU) is used to describe the length of time from fertilization to emergence. One thermal unit is defined as one degree above freezing for a 24-hour period, and is a measurement of the daily average water temperature (Kelley et al. 1985). For example, 1,000^{o}C ATU is achieved through 50 days when daily water temperature averages 20^{o}C (52^{o}F). The reported optimum water temperature for incubation ranges from 41 to 57^{o}F (5-13.9^{o}C; Bjornn and Reiser 1991; Moyle 2002). DFG (1998) stated that in the Sacramento River drainage, 1550^{o}F ATU is required from fertilization to emergence for spring-run Chinook salmon. Armour (1991), citing a personal communication with T. Levendofske (Superintendent of Rapid River Hatchery, Riggins, ID) stated that for Chinook salmon 850^{o}F (454^{o}C) ATU is required for hatching and an additional 750^{o}F (399^{o}C) ATU is required for emergence from gravel. In the

Pacific Northwest, the criterion used for predicting emergence timing varies geographically. The Alaska Department of Fish and Game (2003) reported that 1,650 to 1,830°F (900-1,000°C) ATU is required for emergence; Oregon Department of Fish and Wildlife uses an ATU index value of 1,650°F; and Fisheries and Oceans Canada uses 1,650 to 1,742°F (900-950°C). Predicting the length of time between fertilization and emergence is difficult due to temporal and spatial variation in climatic and physical conditions. Moyle (2002) reported that Chinook salmon incubation times range from 40 to 60 days when water temperatures range from 41 to 55.4°F (5-13°C). Data and information concerning the duration of egg incubation for Chinook salmon in the lower Feather River are unavailable.

Redd superimposition rates can be estimated using various indices. Sommer et al. (2001) used the following superimposition index (SI) to estimate redd superimposition rates in the lower Feather River:

$$SI = \frac{\left(Escapement\ Estimate * Sex\ Ratio\right)}{\left(Spawning\ Area\ \ ft^2 / Mean\ Redd\ Size\ ft^2\right)}$$

The escapement estimate and sex ratio (also referred to as female proportion) are typically calculated using carcass survey data. The spawning area, or the area disturbed by spawning salmon, and the mean redd size are typically quantified through field measurements or by using aerial photographs. When these options are not available, literature reviews are conducted to determine appropriate coefficients. The mean dimensions of Chinook salmon redds reportedly varies geographically as well as between runs (Healey 1991). Differences in the reported mean size of Chinook salmon redds may also be a function of measurement methodology (Healey 1991). For example, field measurements might lead to smaller redd areas than measurements obtained from aerial photographs due to difficulties in the field identification of the tail spill and head of newly constructed redds, particularly if the redds are irregularly shaped (Snider and Vyverberg 1996). Superimposition rates are usually reported as index values, and because redd size is a variable within the SI equation, the methods used to calculate redd size can be highly influential. When measurement methodologies are not standardized between systems, and between years within systems, comparisons cannot be made, and the temporal and spatial magnitude of redd superimposition cannot be confidently assessed. Burner (1951) studied three tributaries of the Columbia River and, using field measurement techniques, reported that the grand mean in size of fall-run Chinook salmon redds was 53.5 ft^2. Chapman et al. (1986) studied the Hanford reach of the Columbia River and, using field measurement techniques, reported that the grand mean in size of fall-run Chinook salmon redds was 184.1 ft^2. Field measurements and aerial photography were used to delineate mean redd size of fall-run Chinook salmon in the American River (Snider et al. 1996; Snider and Vyverberg 1996). The grand mean in size of redds calculated from field measurements was reported as 33 ft^2, and the grand mean in size of redds calculated from aerial photography was reported as 190.5 ft^2. The differences in redd area reported by these studies is likely due to synergistic interaction among variables, and serves as a good example for the need to standardize methodologies.

3.0 STUDY OBJECTIVES

3.1 APPLICATION OF STUDY INFORMATION

The original objective of SP-F10 Task 2B was to evaluate the potential effects from the Oroville Facilities operational procedures on the timing, magnitude, and frequency of flows on the distribution of spawning salmonids in the lower Feather River. However, preliminary analysis of flows in the lower Feather River showed little variation in flow rates during the spawning period, effectively eliminating flow as a potential impact source (for further discussion see section 5.0). The objective of Task 2B was re-scoped to evaluate the effects of the operation of the Oroville Facilities on spawning Chinook salmon in the lower Feather River. Data collected in this task also will serve as a foundation for future evaluations, and development of potential Resource Actions.

3.1.1 Department of Water Resources/Stakeholders

The information from this analysis will be used by DWR and the Environmental Work Group (EWG) to determine how ongoing operations of the Oroville Facilities affects spawning Chinook salmon. Additionally, data collected in this task serves as a foundation for future evaluations and development of potential Resource Actions.

3.1.2 Other Studies

As a subtask of SP-F10, "*Evaluation of Project Effects on Salmonids and Their Habitat in the Feather River Below the Fish Barrier Dam,"* Task 2 evaluates the effects of operation at the Oroville Facilities on the spawning, incubation, and initial rearing period of salmonids in the lower Feather River. Task 2A evaluates the potential project effects on spawning and incubation substrate availability and suitability for salmonids. Task 2C evaluates the effects of water temperatures on the distribution of spawning salmonids, and on egg and alevin survival. Task 2D evaluates the effects of flow fluctuations on redd dewatering. The original scope of Task 2B was to evaluate the potential effects of operation of the Oroville Facilities on the timing, magnitude, and frequency of flows on the distribution of spawning salmonids. However, because flows were relatively constant and because the potential project effects to spawning steelhead in the lower Feather River were addressed in a separate subtask of SP-F10 (for further discussion see section 5.1), the objective of Task 2B was re-scoped to evaluate the effects of operation of the Oroville Facilities on spawning Chinook salmon in the lower Feather River. For further description of Task 2A, Task 2B, Task 2C, and Task 2D see SP-F10 and associated interim and final reports.

3.1.3 Environmental Documentation

In addition to Section 4.51(f)(3) of 18 CFR, which requires reporting of certain types of information in the FERC application for license of major hydropower projects (FERC 2001), it may be necessary to satisfy the requirements of the National Environmental Policy Act (NEPA), and the ESA. Because FERC has the authority to grant an operating license to DWR for continued operation of the Oroville Facilities, discussion is required to identify the potential impacts of the project on many types of resources, including fish, wildlife, and botanical resources. In addition, NEPA requires discussion of any anticipated continuing impact from on-going and future operations. To satisfy NEPA and the ESA, DWR is preparing a Preliminary Draft Environmental Assessment (PDEA) to attach to the FERC license application, which shall include information provided by this study plan report.

3.1.4 Settlement Agreement

In addition to statutory and regulatory requirements, SP-F10 Task 2B could provide information to aid in the development of potential Resource Actions to be negotiated during the settlement process. Additionally, information obtained from analysis on the effects of operation of the Oroville Project on spawning Chinook salmon could be used to determine operating procedures negotiated during the settlement process.

4.0 METHODOLOGY

4.1 DATA COLLECTION

Chinook salmon carcass surveys were conducted by DWR in the lower Feather River from September 5, 2000 through December 14, 2000 (15 survey weeks), from September 10, 2001 through December 13, 2001 (15 survey weeks), from September 3, 2002 through December 19, 2002 (16 survey weeks), and from September 2, 2003 through December 16, 2003 (16 survey weeks). The carcass surveys involved two separate components: mark-recapture surveys and CWT surveys. Separate crews conducted the two surveys concurrently, but independent of each other. In this report, reference to carcass surveys includes both the mark-recapture and the CWT surveys. Otherwise, each survey type will be referenced as either the mark-recapture survey or the CWT survey. The study area was divided into two reaches: the LFC extended from the Fish Barrier Dam (RM 67.25) downstream to the Thermalito Afterbay Outlet (RM 59), and the HFC extended from the Thermalito Afterbay Outlet downstream to Gridley Bridge (RM 51). In 2000, the LFC was divided into 5 sections, with each section divided into a variable number of smaller units. Each unit was defined by a single riffle/pool sequence. The HFC was divided into three large sections. In 2001, the LFC contained 24 sections, and the HFC contained 25 sections. Each section was defined by a single riffle/pool sequence. In 2002 and 2003, the LFC and HFC contained 23 sections each, with each section defined by a single riffle/pool sequence. Sections/units for all survey years were delineated using aerial photographs. Section/unit size and the number of sections/units differed between survey years, although the spatial extent and boundaries of the LFC and the HFC remained consistent between survey years. Maps of carcass survey sections for each year are included in Appendix A.

4.1.1 Chinook Salmon Mark-Recapture Carcass Survey

DWR staff surveyed each river section/unit completely, searching for taggable Chinook salmon carcasses, and recording appropriate information. Taggable carcasses were defined as any individual that appeared to be dead less than a week. In general, recently deceased salmon were firmer (not mushy) and usually had clear eyes or pinkish gills. Darkness, discoloration, and fungus were not reliable indicators of freshness. All taggable carcasses were tagged with a hog ring, a unique combination of colored flagging defining the survey week, and a numbered metal tag. Data recorded for each tagged carcass included date, flagging color combination, metal tag number, river section/unit, FL (cm), age class (adult or grilse), sex, egg retention, release location, and presence or absence of an adipose fin clip. Adult salmon were defined as $\geq$ 26.8 in (68 cm) FL, and grilse salmon were defined as < 26.8 in FL. Egg retention was classified as either spent, partially spent, or unspent. Carcasses were classified as spent if few eggs remained, partially spent if a substantial amount of eggs remained, and unspent if the ovaries appeared nearly full with eggs. Release location was classified as near shore and shallow, near shore and deep, or mid-channel. Shallow water was defined as easily wadeable (usually less than four feet deep). Carcasses found that were tagged during the current survey period were ignored. However, colored flagging from the current survey week was added to carcasses found that were tagged in prior survey weeks, and the appropriate data recorded. After a carcass was tagged, it was returned to the river approximately where it was found. Untaggable carcasses were chopped in half using a machete, and returned to the water. Information recorded for each untaggable carcass found included date, river section/unit, FL (cm), age class (adult or grilse), sex, egg retention, and presence or absence of an adipose fin clip. Some salmon carcasses were ignored during the survey (not counted, chopped or tagged). Such carcasses included: (1) carcasses that had been previously chopped; (2) carcasses that had been filleted or gutted by fisherman; and (3) carcasses that had already been tagged in the current tagging week. Survey crews had no more than four, 10-hour days each week to survey the Feather River from the Fish Barrier Dam to the Gridley Bridge. Each river section/unit received no more than 90 boat minutes of sampling effort each week. If two crews were working one section/unit at the same time, then each crew spent only 45 minutes in the section/unit. Each river section/unit was subdivided into three portions of the channel: left, middle, and right. The channel sub-sections ensured that the entire river section/unit was surveyed. Left and right sub-sections were defined while facing downstream, and were referred to as river left and river right. The left and right boundaries extended from the wetted perimeter of the watercourse out towards the center of the channel as far as could be accessed by wading (roughly four feet deep), but no more than 15 feet out from shore. The amount of time spent working in each sub-section was recorded. Carcasses were tagged in every section/unit and sub-section of the river where they were found. All possible areas of the defined river sections/units were searched for salmon carcasses. Searchable areas included everything from deep pools to shallow backwaters. In the HFC, carcasses were not tagged with numbered metal tags, and only adult salmon carcasses were marked with flagging (no grilse). In addition, in the HFC grilse salmon were chopped and processed as described above for untaggable carcasses.

4.1.1.1 Differences Between the 2000, 2001, 2002, and 2003 Mark-Recapture Survey Data

The protocol used for the mark-recapture carcass survey differed among survey years. Section/unit size and the number of sections/units differed among survey years, although the spatial extent and boundaries of the LFC and the HFC remained consistent among survey years. Metal tags with unique numbers were attached to carcasses only during the 2000 and 2001 surveys. During the 2001, 2002, and 2003 surveys, grilse were sexed only in the sub-sample of fish measured for carcass length. In the HFC during the 2001, 2002, and 2003 surveys, adult and grilse carcasses were tagged, whereas in the HFC during the 2000 survey only adult carcasses were tagged.

4.1.2 Chinook Salmon Coded Wire Tag Sampling

The protocol for the CWT survey differed from the mark-recapture carcass survey. Thus, a description of the CWT protocol is provided. The goal of the CWT sampling was to determine the rate at which CWTs occurred in the population, and to collect all

CWTs that were encountered as part of that sample. A clipped adipose fin indicated the presence of a CWT. The CWT was located in the fish's head, and was collected by removing the entire head behind the gill cover (operculum). In each carcass survey section/unit, the CWT crews checked the first 25 taggable fish encountered, but spent no more than 30 minutes in a single river section/unit. When 30 minutes elapsed, sampling in that section/unit ceased, even if less than 25 taggable carcasses were sampled. Salmon carcasses were sampled (checked for presence of adipose fin clip) without regard to size, sex, or other factors. Fish sampled for CWTs were either chopped or tagged, as described in the mark-recapture carcass survey protocol, so that they could be included in the overall carcass population estimate. Fish having an intact adipose fin (i.e., no CWT), and considered taggable, also were processed as described in the mark-recapture carcass survey protocol. Data recorded for each carcass sampled during the CWT survey included age, FL (cm), sex, spawning condition, adipose fin clip (Yes/No), and CWT head tag number (if applicable). Spawning condition was categorized as either spawned (S) or unspawned (U). Any female salmon retaining one large hand-full of eggs or less was described as spawned (S), otherwise the salmon was categorized as unspawned (U).

The data regarding adipose fin clipped Chinook salmon were used to explore the temporal and spatial spawning distributions of known hatchery reared fish. Salmon having a clipped adipose fin were assumed to be of hatchery origin. In 2000, 2001, and 2003 the total number of carcasses inspected for CWTs was used to calculate the percentage of clipped Chinook salmon that spawned each month and in each reach (LFC, HFC), and by survey period and reach. For each calculated percentage, a 95 percent confidence interval was calculated based on 1,000 bootstrap simulations. Each bootstrap simulation assumed that in each month the numbers of carcasses with an adipose fin clip were binomial distributions with parameters equal to the calculated monthly percentages and the observed sample sizes. In 2002, the total number of carcasses inspected for CWTs was used to calculate the percentage of clipped Chinook salmon over five combinations of temporal and spatial scales: (1) by week and reach; (2) by month, section/unit, and reach; (3) by month and reach; (4) by survey period and reach; and (5) by survey period and study area. For each calculated percentage, a 95 percent confidence interval was calculated based on 1,000 bootstrap simulations. Each bootstrap simulation assumed that in each month the numbers of carcasses with an adipose fin clip were binomial distributions with parameters equal to the calculated monthly percentages and the observed sample sizes.

During the 2002 CWT survey, the head was severed from each Chinook salmon carcass having a clipped adipose fin and placed in a uniquely labeled plastic bag such that each CWT could be linked to the appropriate carcass data. The bags were sent to DFG for extraction and decoding of the CWTs. Information from the CWTs was used to assess the run composition (i.e., spring-run or fall-run) and the age structure of the adipose clipped carcass sample.

4.1.3 Water Temperature Data Collection

Water temperature data loggers were used to measure mean daily water temperatures at 14 sites in the lower Feather River. Nine data loggers were located in the LFC, and 5 were located in the HFC (Figure 4.1-1). Water temperatures were recorded from July 31, 2002 through January 16, 2003. A minimum of 96 data points was collected, at an even interval, during each 24-hour period from each water temperature logging station. In certain instances, water temperature data were unavailable and/or sample dates were inconsistent because of dewatered logging stations, vandalism, or thermograph malfunction. A complete description of the methodology associated with water temperature data collection can be found in Section 7.0, Study Plan (SP)-W6 "*Project Effects on Temperature Regime*" (DWR 2002c). Mean daily water temperatures were determined by reach (LFC, HFC) and survey day by pooling and averaging mean daily water temperatures for each respective reach.

4.2 DATA ANALYSES

4.2.1 Spawning Timing, Spawning Water Temperature Tolerance Values, and Associated Water Temperatures in the Lower Feather River

A literature review was conducted to determine water temperature values most relevant to the spawning and embryo incubation life stage of Chinook salmon. The values were used to assess the effects to spawning Chinook salmon from water temperatures in the lower Feather River. Many publications make statements or cite other literature concerning spawning Chinook salmon thermal tolerances. Evaluation of many of these citings and statements revealed, in many instances, that there were no studies or data substantiating the reported values. Primary data sources, usually from peer-reviewed journals that presented data allowing objective interpretations, and regulatory agency documents were used to delineate water temperature values used for impact assessment and as technical evaluation guidelines.

The timing of Chinook salmon spawning in the lower Feather River was determined by utilizing carcass survey data (see section 1.1.10). In addition, a literature review was conducted to determine the index water temperature tolerance values most relevant to spawning Chinook salmon (see section 1.1.9). Mean daily water temperatures from multiple water temperature data loggers were pooled, by reach (LFC, HFC), to determine the reach specific mean daily water temperatures. Comparison of water temperature data to the thermal tolerance index values outlined for spawning Chinook salmon during the defined spawning time period facilitated identification of time periods when thermal stress may occur, and provided the information necessary to support potential future Resource Action recommendations. The effects of water temperature on spawning Chinook salmon were analyzed separately for the LFC and the HFC because the longitudinal water temperature gradient differed between the two reaches.

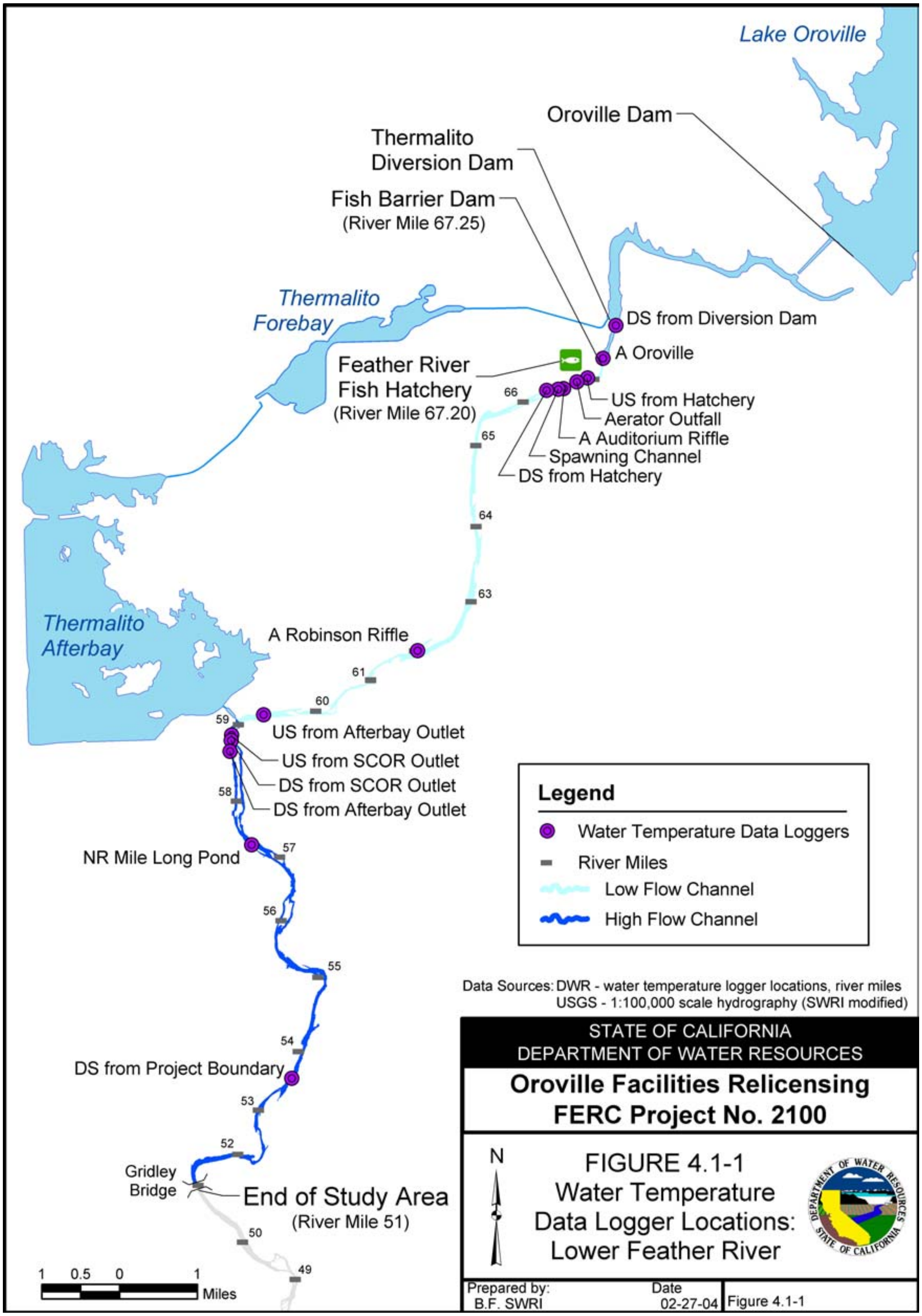


Figure 4.1-1. Water temperature data logger locations in the lower Feather River.

4.2.2 Distribution of Chinook Salmon Carcass Counts

The temporal and spatial distributions of Chinook salmon carcasses in the lower Feather River were similar across carcass survey study years. The 2002 carcass survey data were used as an example to graphically display these distributions. Carcass count totals were summed by survey week and reach in order to display the temporal and spatial distribution of carcasses. Carcass densities for each section/unit were determined by summing carcass count totals by survey month, section/unit, and reach then dividing by the appropriate section/unit area (acre). Carcass count totals were used to calculate the percent cumulative distribution of carcass counts, by study reach and survey day, to graphically explore potential relationships between the timing of spawning and mean daily water temperature. The period during which regression analysis of carcass distribution and water temperature data was performed was determined by the availability of water temperature data. At the time during which regression analysis of water temperature and carcass distribution data was performed, water temperature data were available only for 2002. To smooth the cumulative distribution of carcass counts, the observed percentages were fitted to sigmoidal curves using non-linear regression (minimum least-squares).

4.2.3 Distribution of Chinook Salmon Carcass Lengths

Length-frequency distributions were constructed using the 2000, 2001, 2002, and the 2003 carcass survey data. For each year, length-frequency distributions were constructed by reach and sex. In addition, the 2002 carcass survey data were used to construct box plots by sex, then by reach and sample month. The 2002 data from November and December were pooled due to small sample sizes in December. T-tests were used to test for differences in the 2002 mean carcass length between reaches, by sex, and by sample month.

4.2.4 Sex Ratios

For the 2000, 2001, and 2003 Chinook salmon carcass survey, sex ratio was calculated for each reach (LFC, HFC) by dividing the total number of female carcasses detected by the total number of carcasses detected. The following formula was used to calculate sex ratio estimates:

$$P_F = \frac{C_F}{C_F + C_M}, \text{ where}$$

P_F = percentage of females,
C_F = total number of female carcasses detected,
C_M = total number of male carcasses detected.

Standard errors and 95 percent confidence intervals were calculated using 1,000 bootstrap simulations per case to allow for a comparison of the estimates between reaches. Each bootstrap simulation assumed that in each reach, females were distributed as a binomial distribution, with parameters equal to the estimated female proportion and the observed sample sizes.

For the 2002 Chinook salmon carcass survey, sex ratios were calculated using two methods. The first method did not include grilse sex ratios in the estimate formulas, but the second method did. For each method, sex ratios were calculated for each reach using the formula described above. Standard errors and 95 percent confidence intervals were calculated using 1,000 bootstrap simulations per case to allow for a comparison of the estimates between reaches. Each bootstrap simulation assumed that in each reach, females were distributed as a binomial distribution, with parameters equal to the estimated female proportion and the observed sample sizes. The spatial distribution of sex ratios was plotted graphically by calculating the percentage of females for each section/unit.

4.2.5 Spawning Escapement Estimates in the Lower Feather River

The Schaefer method of analyzing mark-recapture data (Schaefer 1951), as modified by Taylor (1974), was applied to the carcass survey data to produce spawning escapement estimates. Prior to calculating estimates, carcass survey data were processed and the basic Schaefer variables calculated for each reach. The variables included the number of fresh carcasses tagged in tagging week *i* and recovered in recovery week *j* ($R_{i,j}$), the number of fresh carcasses observed and tagged in tagging week *i* (T_i), the total number of tags released in tagging week *i* that were recovered by the end of the carcass survey (R_i), the number of tags recovered in recovery week *j* (R_j), and the total number of carcasses counted in recovery week *j* (C_j). The term C_j included the number of decayed carcasses observed and chopped, the number of fresh carcasses observed and tagged, the number of fresh carcasses observed and chopped, and the number of tagged carcasses recovered that week.

The Schaefer variables were used to calculate an estimate of the Chinook salmon spawning escapement in the lower Feather River. For each survey year, spawning escapement estimates were calculated by year, by reach, and by week and reach. The experimental design did not allow for temporal spawning escapement estimates other than by week, or spawning escapement estimates at scales smaller than by reach. Reach-specific spawning escapement estimates were calculated as:

$$\hat{N} = \hat{N}_j - \left(\sum_{i=2} T_i \right) + T_1 \text{, where}$$

$\hat{N}$ = spawning escapement estimate,
$\hat{N}_j$ = the estimated portion of the spawning escapement available to recapture in recovery week *j.*

Weekly spawning escapement estimates were calculated as:

$$\hat{N}_i = \sum_j \left(R_{i,j} * \frac{T_i}{R_i} * \frac{C_j}{R_j} \right), \text{ and}$$

$$\hat{N}_j = \sum_i \left(R_{i,j} * \frac{T_i}{R_i} * \frac{C_j}{R_j} \right), \text{ where}$$

$\hat{N}_i$ = is the estimated portion of the spawning escapement available for marking in tagging week *i.*

Yearly spawning escapement estimates were calculated by summing the estimates for each reach.

4.2.6 Instream Flow and Spawning Habitat Availability

A full description of the methodology and study design used for the instream flow/habitat analysis component of SP-F10 Task 2B can be located in the final report for SP-F16 Phase 2 *"Evaluation of Project Effects on Instream Flows and Fish Habitat"* (DWR 2002b). Data were combined in the PHABSIM computer model to compute the WUA index to habitat suitability for spawning Chinook salmon in the lower Feather River. Data were pooled for each reach (LFC, HFC), and habitat availability-flow curves were generated.

4.2.7 Pre-Spawn Mortality

4.2.7.1 Pre-Spawn Mortality Estimates

For the 2000, 2001, and 2003 mark-recapture and CWT survey, egg retention was determined for a sub-sample of the female carcasses detected. Carcasses were classified as spent if few eggs remained, partially spent if a substantial amount of eggs remained, and unspent if the ovaries appeared nearly full with eggs. Egg retention was described as spawned (S), which included the spent and partially spent categories, or unspawned (U). Pre-spawn mortality was calculated as the percentage of the total sample of female carcasses that were classified as unspawned. The temporal and spatial distributions of pre-spawn mortality were assessed by sample week and survey reach (LFC, HFC), and by study period and survey reach.

For the 2002 mark-recapture and CWT survey, the temporal and spatial distributions of pre-spawn mortality were assessed by: (1) survey week and reach; (2) survey month, section/unit, and reach; (3) by survey month and reach; and (4) by survey year, section/unit, and reach. For pre-spawn assessment by week and reach, and by month and reach, a 95 percent confidence interval was calculated based on 1,000 bootstrap simulations. Each bootstrap simulation assumed that for each month, unspawned females were distributed as a binomial distribution with parameters equal to the estimated pre-spawning mortality/100 and the observed sample sizes.

4.2.7.2 Pre-Spawn Mortality Regression Analyses

Regression analysis was used to explore the weekly pre-spawn mortality patterns of the 2002 carcass survey data. Water temperature and spawning escapement estimates were used as the two main factors in the regression analyses. Water temperature was represented by six variables. Mean weekly water temperature, for each reach, was calculated by pooling the mean daily water temperatures. The calculations were based on water temperatures corresponding to two, three, and four weeks prior to each survey week (*AT2, AT3, and AT4*). Weekly averages of the variances of mean daily water temperatures, for each reach, were calculated based on water temperatures corresponding to two, three, and four weeks prior to each survey week (*AVarT2, AVarT3, AVarT4*). The variables representing the weekly spawning escapement estimates (*Escapement*) corresponded with the weekly Schaeffer estimates calculated using the 2002 carcass survey data. The survey weeks (*Week* = 1, 2..., 16) were kept in the regression analyses as a variable representing a temporal component, and because of factors not accounted for by the other variables. Because weekly pre-spawn mortality estimates (*P*) were based on an indicator variable (presence or absence of spawned ovaries), the shape of their response function was that of a tilted S with asymptotes at 0 and 1. Thus, for the regression analyses, the LFC and HFC weekly pre-spawn mortality estimates were linearized using a logit transformation (pp. 361 to 367 *in* (Neter et al. 1985):

$$Logit\ P = \ln\left[\frac{P}{1-P}\right] = \ln\left(\frac{(Unspawned\ Females / Total\ Females)}{1-(Unspawned\ Females / Total\ Females)}\right).$$

When the calculated weekly pre-spawn mortality estimates equaled one, their logit was calculated as:

$$Logit\ P_i = 1 - \frac{1}{2n_i}\text{, where}$$

n_i = sample size the estimate was based upon.

The approach avoids discarding estimates with values of one. A weighted least squares procedure was used in the regression analyses because the logit transformation, while linearizing the response variable, does not eliminate the unequal variances of the error terms. Each observation was given a weight equal to the inverse of the variances estimated through the use of 1,000 bootstrap simulations, with each bootstrap simulation assuming a binomial distribution. For each reach, weighted least-squares regression was applied to eight simple models that related Logit P to each of the eight explanatory variables (Week, Escapement, AT2, AT3, AT4, AVarT2, AVarT3, and AVarT4), and to two multivariate models: (1) the full model (FM) that combined the eight explanatory variables; and (2) the reduced model (STM) that was selected through stepwise multiple regression. The stepwise multiple regression procedure was applied to select the most parsimonious model.

4.2.8 Redd Superimposition Estimates

Aerial photographs and/or field measurements of the area disturbed by spawning Chinook salmon in the lower Feather River were unavailable for 2000, 2001, and 2002, and a redd superimposition index (SI) could not be developed for these years. Indices were developed for each river reach using carcass survey data collected in 1995 and 2003. The methodologies and results reported for the 1995 superimposition analyses were taken directly from Sommer et al. (2001). The following equation was used to develop the SI:

$$SI = \frac{(Escapement\ Estimate * Sex\ Ratio)}{(Spawning\ Area\ ft^2\ /\ Mean\ Redd\ Size\ ft^2)}.$$

Spawning escapement estimates were calculated using carcass survey data collected in 1995 and 2003. For the 1995 carcass survey, it was assumed that an equal number of male and female Chinook salmon spawned in the lower Feather River. Therefore, 0.5 represented the sex ratio variable in the SI for 1995. Two separate SI were developed for the 2003 carcass survey data. For comparative purposes with the 1995 indices, 0.5 represented the sex ratio variable used to develop one set of SI. In addition, sex ratio data from the 2003 survey was used to determine sex ratio and to develop a second set of superimposition indices. For the methodology associated with how the sex ratio from the 2003 carcass survey was developed refer to section 4.2.4. The mean redd size was assumed to be 55 ft^2 for both the 1995 and 2003 calculations, based on the literature review conducted by Bell (1991). For the 1995 SI, the spawning area was estimated using aerial photographs taken of the entire study area in November 1995. Ground-based observations were made within 24 hours of the date of the flight to check the accuracy of the methods. Photographs of sites containing redds were enlarged to a scale of 1:600. The total disturbed area, referred to as total spawning area, was delineated on the prints relative to habitat boundaries delineated on habitat maps (see Sommer et al. (2001) for a description of the development of the habitat maps). The area estimates were calculated by digitizing these maps using AUTOCAD. The results were quantified by river reach. For the 2003 SI, the area disturbed by spawning Chinook salmon was characterized during two separate surveys. The LFC was surveyed on November 12, 2003, and the HFC was surveyed on December 3, 2003. Visual delineations were made of areas disturbed by spawning Chinook salmon by repeatedly drifting through riffles. Once crew members agreed on appropriate delineations, polygon shapefiles, representing disturbed areas, were collected using handheld GPS receivers. The shapefiles were then converted to a personal geodatabase feature class in a Geographic Information System (GIS), and added to an ArcMap document. The disturbed area was calculated in the GIS for the LFC and for the HFC. For both 1995 and 2003, it was not possible to identify individual redds because of the large numbers of fish spawning in relatively few areas. Therefore, the spawning area utilized in the calculation of the SI was quantified by delineating areas that appeared to be disturbed by spawning Chinook salmon, rather than calculating areas of redds. During the 1995 and 2003 surveys, it is likely that some disturbed areas did not represent redds. Results from these surveys should be considered an estimate of the maximum amount of area used for spawning, and results may underestimate redd superimposition rates.

5.0 STUDY RESULTS

5.1 DEFINITION OF WATER TEMPERATURE INDICES FOR SPAWNING CHINOOK SALMON

A literature review to determine the effects of water temperature on spawning Chinook salmon produced many different water temperature values, and using all of the values as evaluation criteria is not efficient or reasonable. In certain instances, chosen values were rounded up or down but were still very similar to, and representative of, reported water temperature values. The water temperature index values selected in this report as criteria for impact assessment were chosen because they represent the values most commonly recommended and suggested by researchers and regulatory agencies, and because the range of selected values encompasses the range of values most often referenced in available literature. For purposes of this report, 56°F (13.3°C), 58°F (14.4°C), 60°F (15.6°C), 62°F (16.7°C), and 64°F (17.8°C) were used as index values to assess the potential thermal impacts from operation of the Oroville Facilities on spawning Chinook salmon in the lower Feather River (see section 1.1.9).

5.2 DEFINITION OF THE SPAWNING TIME PERIOD FOR CHINOOK SALMON IN THE LOWER FEATHER RIVER

An estimate of the time period during which Chinook salmon spawn in the lower Feather River was determined from carcass survey data. A literature review was conducted to determine the lag time between initiation of spawning and carcass detection to allow for a more accurate determination of the actual spawning period. Based on available literature, it was determined that, in general, three weeks elapse between the time that a Chinook salmon initiates spawning and the time that it dies. DWR detected salmon carcasses on September 2, the first day that carcass surveys were conducted. For purposes of this report, a 3-week lag time was added to the date at which carcasses were first detected. Therefore, it was assumed that Chinook salmon begin spawning on approximately August 12 in the lower Feather River. DWR detected salmon carcasses on December 19, which was the last day they conducted carcass surveys. Therefore, for purposes of this report, Chinook salmon spawning was assumed to conclude on approximately December 19 in the lower Feather River. Empirical data suggesting that Chinook salmon spawning in the lower Feather River occurs during a period other than from August 12 through December 19 are unavailable.

5.3 WATER TEMPERATURES IN THE LOWER FEATHER RIVER DURING THE DEFINED SPAWNING PERIOD FOR CHINOOK SALMON

Mean daily water temperatures during the 2002 Chinook salmon spawning period, the defined water temperature index values, and the defined spawning time period for Chinook salmon in the lower Feather River are shown in Figure 5.3-1.

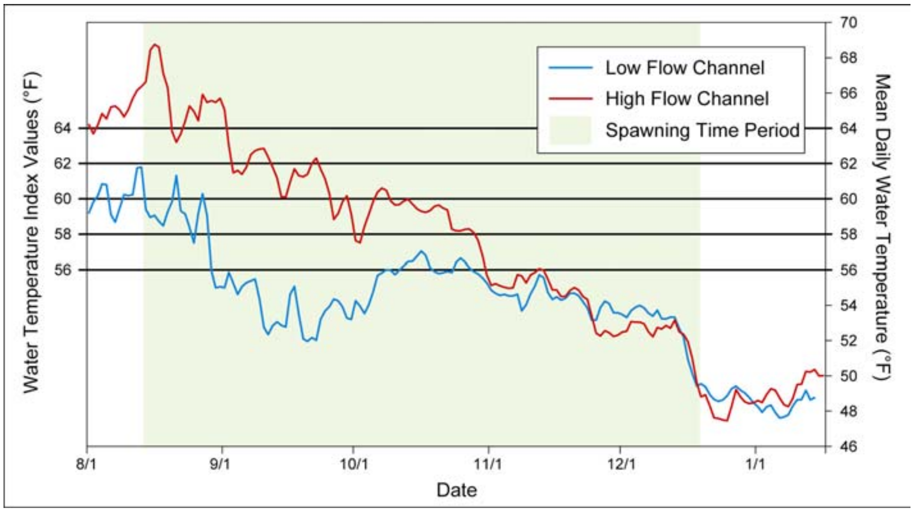


Figure 5.3-1. Mean daily water temperature (July 31, 2002 through January 16, 2003), water temperature index values, and the Chinook salmon spawning period in the lower Feather River. See text for explanation of water temperature index value selection.

5.3.1 Water Temperatures in the LFC of the Lower Feather River During the Defined Chinook Salmon Spawning Period

Mean daily water temperatures in the LFC rarely exceeded 60°F (15.6°C) during the time period that water temperature data were available. Mean daily water temperatures were between 60 to 62°F (15.6-16.7°C) on ten occasions in August, and three of these days coincided with the defined Chinook salmon spawning period. During the remainder of the defined spawning time period, mean daily water temperatures remained below 56°F (13.3°C), with the exception of eleven days in October when mean daily water temperatures ranged from 56 to 58°F (13.3-14.4°C). The highest mean daily water temperature recorded in the LFC during the 2002 Chinook salmon spawning period was 61.8°F (16.6°C) on August 13, 2002.

5.3.2 Water Temperatures in the HFC of the Lower Feather River During the Defined Chinook Salmon Spawning Period

Mean daily water temperatures in the HFC remained below 60°F (15.6°C) from September 26, 2002 through January 16, 2003 (with the exception of one day in late September and three days in early October), and remained below 56°F (13.3°C) from October 31, 2002 through January 16, 2003. Mean daily water temperatures exceeded 62°F (16.7°C) from July 31, 2002 through August and most of early September. Mean daily water temperatures exceeded 64°F (17.8°C) during most of August. The highest mean daily water temperature recorded in the HFC was 68.8°F (20.4°C) on August 16, 2002. During the defined Chinook salmon spawning period, mean daily water temperatures in the HFC remained below 60°F (15.6°C) for 64 percent of the time.

5.4 CHINOOK SALMON MARK-RECAPTURE CARCASS SURVEY

The empirical results from the 2000 mark-recapture Chinook salmon carcass survey are shown in Table 5.4-1. The surveys took place for 15 weeks beginning on September 5, 2000, and concluding on December 14, 2000. The combined results for the LFC and the HFC show that 50,128 carcasses were detected during the survey period. Of these, 6,246 carcasses were tagged with week-specific flagging, 23,251 carcasses were classified as male, and 26,877 were classified as female. A sub-sample of 6,386 carcasses was measured using FL (cm). Of these, 2,447 carcasses were male, 3,936 carcasses were female, and 3 carcasses were not sexed. Egg retention was determined for 3,935 female carcasses, and described as either spawned (S; 2,610), which included the spent and partially spent categories, or not spawned (U; 1,325).

Table 5.4-1. Empirical results from the 2000 mark-recapture and CWT Chinook salmon carcass survey in the lower Feather River.

Low Flow Channel (LFC)				
Counted carcasses	41,908			
Tagged carcasses	5,375			
Sexed carcasses	M	F	M+F	
	19,172	22,736	41,908	
Length measurements	M	F	UK	M+F
	2,037	3,468	3	5,505
Presence of adipose clip	Y	N	Total	
	188	5,344	5,532	
Female spawning status	S	U	Total	
	2,325	1,144	3,469	
High Flow Channel (HFC)				
Counted carcasses	8,220			
Tagged carcasses	871			
Sexed carcasses	M	F	M+F	
	4,079	4,141	8,220	
Length measurements	M	F	UK	M+F
	410	468	0	878
Presence of adipose clip	Y	N	Total	
	13	867	880	
Female spawning status	S	U	Total	
	285	181	466	
Survey Area (LFC + HFC)				
Counted carcasses	50,128			
Tagged carcasses	6,246			
Sexed carcasses	M	F	M+F	
	23,251	26,877	50,128	
Length measurements	M	F	UK	M+F
	2,447	3,936	3	6,383
Presence of adipose clip	Y	N	Total	
	201	6,211	6,412	
Female spawning status	S	U	Total	
	2,610	1,325	3,935	

The empirical results from the 2001 mark-recapture Chinook salmon carcass survey are shown in Table 5.4-2. The survey took place for 15 weeks beginning on September 10, 2001, and concluding on December 13, 2001. The combined results for the LFC and the HFC show that 54,278 carcasses were detected during the survey period. Of these, 4,972 carcasses were tagged with week-specific flagging, 20,671 carcasses were classified as male, 31,399 carcasses were classified as female, and 2,205 carcasses were classified as grilse. A sub-sample of 5,395 carcasses was measured using FL (cm). Of these, 3,820 carcasses were male, 1,573 carcasses were female, and 2 carcasses were not sexed (grilse salmon were sexed in this sub-sample). Egg retention was determined for 3,622 female carcasses, and described as either spawned (S; 1,858) or not spawned (U; 1,764).

Table 5.4-2. Empirical results from the 2001 mark-recapture and CWT Chinook salmon carcass surveys in the lower Feather River.

Low Flow Channel (LFC)				
Counted carcasses	41,678			
Tagged carcasses	4,038			
Sexed carcasses	M	F	Grilse	M+F
	15,394	25,024	1,258	40,418
Length measurements	M	F	UK	M+F
	3,145	1,200	2	4,345
Presence of adipose clip	Y	N	Total	
	221	4,038	4,259	
Female spawning status	S	U	Total	
	1,465	1,512	2,977	
High Flow Channel (HFC)				
Counted carcasses	12,600			
Tagged carcasses	934			
Sexed carcasses	M	F	Grilse	M+F
	5,277	6,375	947	11,652
Length measurements	M	F	UK	M+F
	675	373	---	1,048
Presence of adipose clip	Y	N	Total	
	25	934	959	
Female spawning status	S	U	Total	
	393	252	645	
Survey Area (LFC + HFC)				
Counted carcasses	54,278			
Tagged carcasses	4,972			
Sexed carcasses	M	F	Grilse	M+F
	20,671	31,399	2,205	52,070
Length measurements	M	F	UK	M+F
	3,820	1,573	2	5,393
Presence of adipose clip	Y	N	Total	
	246	4,972	5,218	
Female spawning status	S	U	Total	
	1,858	1,764	3,622	

The empirical results from the 2002 mark-recapture Chinook salmon carcass survey are shown in Table 5.4-3. The survey took place for 15 weeks beginning on September 3, 2002, and concluding on December 19, 2002. The combined results for the LFC and the HFC show that 47,160 carcasses were detected during the survey period, of which 8,678 were tagged with week-specific flagging. A random sub-sample of 43,806 carcasses was classified as male (16,789), female (23,108), or grilse (3,909). A sub-sample of 5,829 carcasses was measured using FL (cm). Of these, 2,300 carcasses were male, 3,524 carcasses were female, and 5 carcasses were not sexed (grilse salmon were sexed in this sub-sample). Egg retention was determined for 3,484 female carcasses, and described as either spawned (S; 2,002) or not spawned (U; 1,482).

Table 5.4-3. Empirical results from the 2002 mark-recapture and CWT Chinook salmon carcass surveys in the lower Feather River.

Low Flow Channel (LFC)				
Counted carcasses	38,093			
Tagged carcasses	7,101			
Sexed carcasses	M	F	Grilse	M+F
	12,836	19,354	2,907	32,190
Length measurements	M	F	UK	M+F
	1,670	2,727	5	4,397
Presence of adipose clip	Y	N	Total	
	426	4,316	4,742	
Female spawning status	S	U	Total	
	1,442	1,251	2,693	
High Flow Channel (HFC)				
Counted carcasses	8,884			
Tagged carcasses	1,577			
Sexed carcasses	M	F	Grilse	M+F
	3,953	3,754	1,002	7,707
Length measurements	M	F	UK	M+F
	630	797		1,427
Presence of adipose clip	Y	N	Total	
	29	1,006	1,035	
Female spawning status	S	U	Total	
	560	231	791	
Survey Area (LFC + HFC)				
Counted carcasses	47,160			
Tagged carcasses	8,678			
Sexed carcasses	M	F	Grilse	M+F
	16,789	23,108	3,909	39,897
Length measurements	M	F	UK	M+F
	2,300	3,524	5	5,824
Presence of adipose clip	Y	N	Total	
	455	5,322	5,777	
Female spawning status	S	U	Total	
	2,002	1,482	3,484	

The empirical results from the 2003 mark-recapture Chinook salmon carcass survey are shown in Table 5.4-4 . The survey took place for 16 weeks beginning on September 2, 2003, and concluding on December 17, 2003. The combined results for the LFC and the HFC show that 39,709 carcasses were detected during the survey period, of which 8,356 were tagged with week-specific flagging. A random sub-sample of 31,352 carcasses was classified as male (11,904), female (17,945), or grilse (1,503). A sub-sample of 6,087 carcasses was measured using FL (cm). Of these, 2,039 carcasses were male, 4,035 carcasses were female, and 13 carcasses were not sexed (grilse salmon were sexed in this sub-sample). Egg retention was determined for 4,026 female carcasses, and described as either spawned (S; 2,379) or not spawned (U; 1,647).

Table 5.4-4. Empirical results from the 2003 mark-recapture and CWT Chinook salmon carcass surveys in the lower Feather River.

Low Flow Channel (LFC)				
Counted carcasses	29,785			
Tagged carcasses	6,602			
Sexed carcasses	M	F	Grilse	M+F
	8,472	13,594	1,116	22,066
Length measurements	M	F	UK	M+F
	1,491	3,039	8	4,530
Presence of adipose clip	Y	N	Total	
	379	4,123	4,502	
Female spawning status	S	U	Total	
	1,631	1,403	3,034	
High Flow Channel (HFC)				
Counted carcasses	9,924			
Tagged carcasses	1,754			
Sexed carcasses	M	F	Grilse	M+F
	3,432	4,351	387	7,783
Length measurements	M	F	UK	M+F
	548	996	5	1,544
Presence of adipose clip	Y	N	Total	
	32	1,512	1,544	
Female spawning status	S	U	Total	
	748	244	992	
Survey Area (LFC + HFC)				
Counted carcasses	39,709			
Tagged carcasses	8,356			
Sexed carcasses	M	F	Grilse	M+F
	11,904	17,945	1,503	29,849
Length measurements	M	F	UK	M+F
	2,039	4,035	13	6,074
Presence of adipose clip	Y	N	Total	
	411	5,635	6,046	
Female spawning status	S	U	Total	
	2,379	1,647	4,026	

5.5 CHINOOK SALMON CWT SURVEY

The results from the 2000 CWT survey are shown in Table 5.4-1. The combined results for the LFC and the HFC show that 6,412 Chinook salmon carcasses were inspected for a clipped adipose fin. Of these, 201 carcasses had a clipped adipose fin, and 6,211 carcasses had an intact adipose fin. In the LFC, 5,532 carcasses were inspected for a clipped adipose fin. Of these, 188 carcasses had a clipped adipose fin, and 5,344 carcasses had an intact adipose fin. In the HFC, 880 carcasses were inspected for a clipped adipose fin. Of these, 13 carcasses had a clipped adipose fin, and 867 carcasses had an intact adipose fin.

The temporal (month) and spatial (survey reach) distribution of the calculated percentage of inspected Chinook salmon carcasses having a clipped adipose fin, 95 percent confidence intervals, and sample sizes are shown in Figure 5.5-1. The percentage of inspected carcasses having a clipped adipose fin was highest in September (8.8 percent in the LFC, and 11.3 percent in the HFC), and then decreased steadily through November. The decreasing trend in the percentage of adipose fin-clipped fish may have continued through December, but sample sizes were too small to provide accurate calculations. The spatial distribution of Chinook salmon of known hatchery origin may be best reflected in October because of the larger sample sizes and tighter confidence intervals. The spatial distribution of Chinook salmon of known hatchery origin for the entire survey period is similar to the distribution in October, with the LFC having a higher percentage of inspected carcasses displaying a clipped adipose fin (approximately 3.5 percent in the LFC, and 1.5 percent in the HFC).

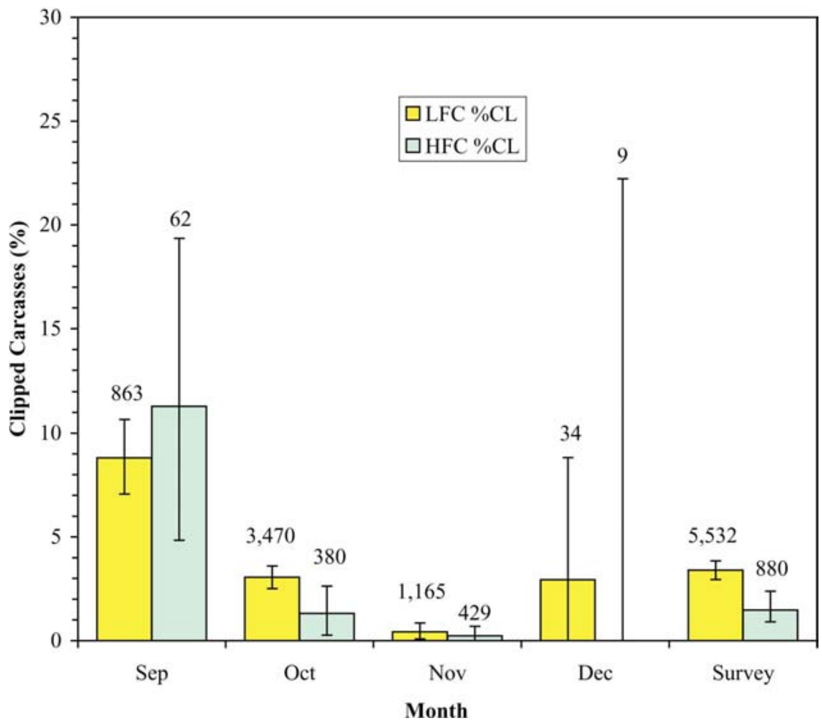


Figure 5.5-1. Percentage of carcasses having a clipped adipose fin, by survey month and reach, during the 2000 CWT survey in the lower Feather River.
Note: Error bars indicate the 95% confidence intervals, and the numbers represent sample sizes.

The results from the 2001 CWT survey are shown in Table 5.4-2. The combined results for the LFC and the HFC show that 5,218 Chinook salmon carcasses were inspected for a clipped adipose fin. Of these, 246 carcasses had a clipped adipose fin, and 4,972 carcasses had an intact adipose fin. In the LFC, 4,259 carcasses were inspected for a clipped adipose fin. Of these, 221 carcasses had a clipped adipose fin, and 4,038 carcasses had an intact adipose fin. In the HFC, 959 carcasses were inspected for a clipped adipose fin. Of these, 25 carcasses had a clipped adipose fin, and 934 carcasses had an intact adipose fin.

The temporal (month) and spatial (survey reach) distribution of the calculated percentage of inspected Chinook salmon carcasses having a clipped adipose fin, 95 percent confidence intervals, and sample sizes are shown in Figure 5.5-2. The percentage of inspected carcasses having a clipped adipose fin was highest in September (11.3 percent in the LFC, and 18.8 percent in the HFC), and then decreased steadily through November. The spatial distribution of Chinook salmon of known hatchery origin for the entire survey period is similar to the distribution in October, with the LFC having a higher percentage of inspected carcasses displaying a clipped adipose fin (approximately 6 percent in the LFC, and 3 percent in the HFC).

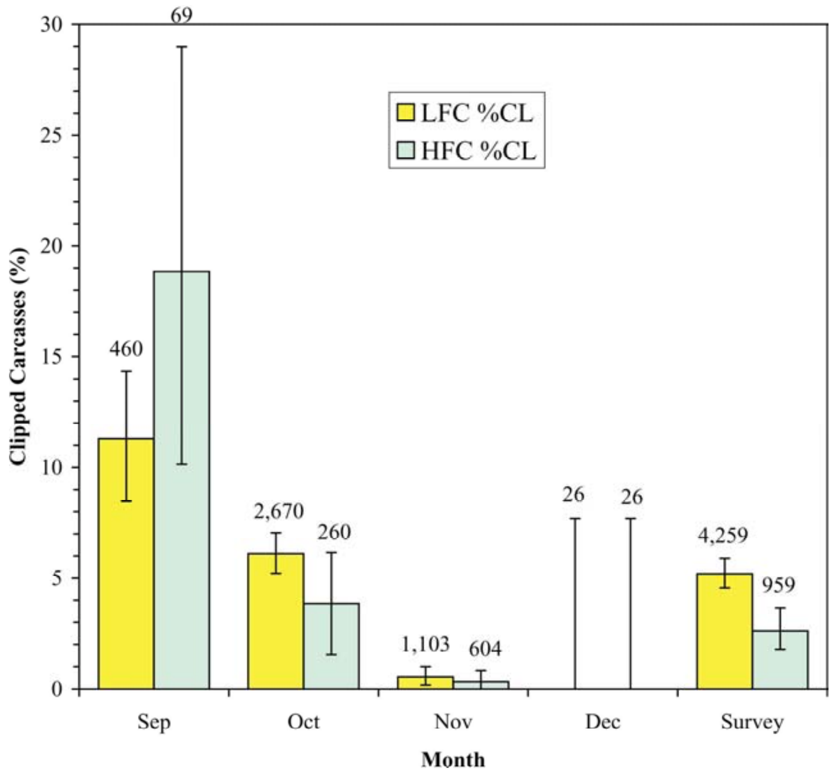
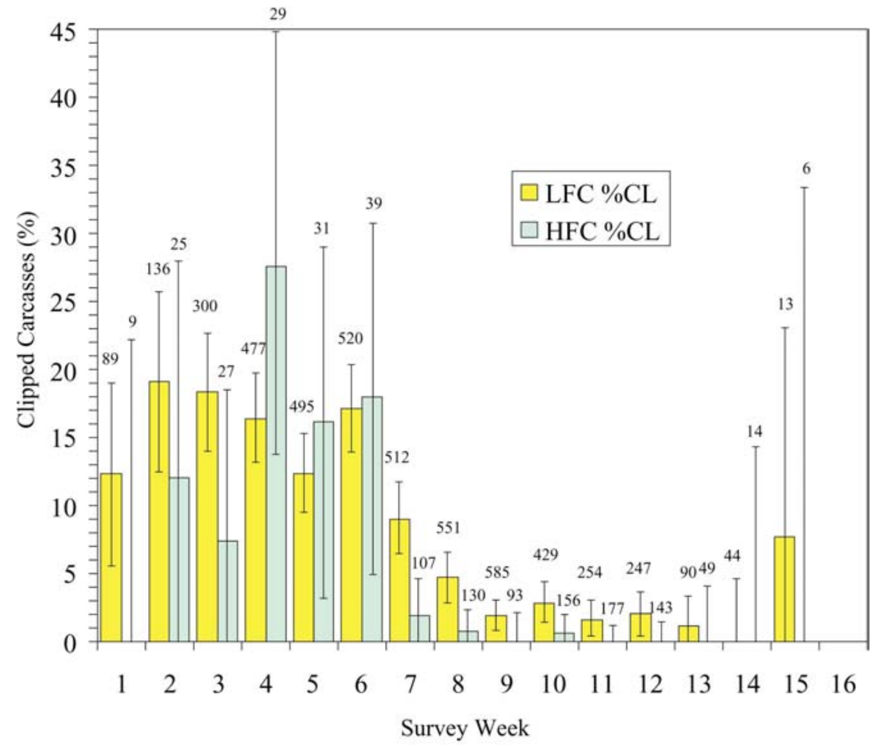


Figure 5.5-2. Percentage of carcasses having a clipped adipose fin, by survey month and reach, during the 2001 CWT survey in the lower Feather River.
Note: Error bars indicate the 95% confidence intervals, and the numbers represent sample sizes.

The results from the 2002 CWT survey are shown in Table 5.4-3. The combined results for the LFC and the HFC show that 5,777 Chinook salmon carcasses were inspected for a clipped adipose fin. Of these, 455 carcasses had a clipped adipose fin, and 5,322 carcasses had an intact adipose fin. In the LFC, 4,742 carcasses were inspected for a clipped adipose fin. Of these, 426 carcasses had a clipped adipose fin, and 4,316 carcasses had an intact adipose fin. In the HFC, 1,035 carcasses were inspected for a clipped adipose fin. Of these, 29 carcasses had a clipped adipose fin, and 1,006 carcasses had an intact adipose fin.

The percentage of inspected carcasses having a clipped adipose fin in 2002 presented by survey week and reach, 95 percent confidence intervals, and sample sizes are shown in Figure 5.5-3. In the LFC, the weekly percentages of inspected carcasses having a clipped adipose fin were greatest in weeks one through six when percentages ranged from 12.3 percent (week 5) to 19.1 percent (week 2). Calculated percentages decreased during the subsequent survey weeks. In the HFC, the weekly percentages of inspected carcasses having a clipped adipose fin were greatest in weeks one through six, and then decreased during the subsequent survey weeks. In general, the percentages of inspected carcasses having a clipped adipose fin were higher in the LFC than in the HFC.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
From	9/3	9/9	9/16	9/23	9/30	10/7	10/14	10/21	10/28	11/4	11/11	11/18	11/25	12/2	12/9	12/16
To	9/5	9/12	9/19	9/26	10/4	10/10	10/17	10/25	10/31	11/8	11/14	11/21	11/27	12/5	12/11	12/19

Figure 5.5-3. Percentage of carcasses having a clipped adipose fin, by survey week and reach, during the 2002 CWT survey in the lower Feather River.
Note: Error bars indicate the 95% confidence intervals, and the numbers represent sample sizes.

The percentage of inspected carcasses having a clipped adipose fin in 2002 presented by month, section/unit, and survey reach are shown in Figures A-2 through A-5 in Appendix A. The number of inspected carcasses with and without a clipped adipose fin varied considerably by month, section/unit, and survey reach.

In the LFC, the highest percentage of inspected carcasses having a clipped adipose fin were generally located in those sections/units adjacent to the Feather River Hatchery, just upstream of Eye Riffle, and just upstream of the Thermalito Afterbay Outlet (Figures A-2 through A-5). In September, the highest percentage (≥16 percent) of inspected carcasses with clipped adipose fins included section/unit 2, 3, 4, 6, 8, 9, 10, 11, 14, 19, 21, and 23 (Figure A-2). In October, the percentage of adipose fin-clipped carcasses decreased, with the highest percentage located in section/unit 1 (17 percent; except section 5, but only one carcass was inspected in that section), which was the closest section/unit to the fish hatchery (Figure A-3). The number of carcasses having a clipped adipose fin decreased significantly in November, and by December, only one adipose fin-clipped carcass was detected (section/unit 8). However, sample sizes were much smaller in November and December than in September and October (Figure A-4 and Figure A-5).

In the HFC, the spatial distribution of adipose fin-clipped carcasses appeared random. In September, the highest percentage (≥25 percent) of inspected carcasses with a clipped adipose fin was detected in section/unit 24, 29, 36, 41, and 44 (Figure A-2). In October, percentages decreased, although sample sizes increased, with largest percentages detected in section/unit 25, 37, and 45 (Figure A-3). In November, sample sizes were similar to those in October (Figure A-4), although just one adipose fin-clipped carcass was detected (section/unit 42). In December, sample sizes were very small, and no adipose fin-clipped carcasses were detected (Figure A-5).

In the LFC, sample sizes and percentages of inspected carcasses with a clipped adipose fin were greatest in September and October, with the largest percentage of adipose fin-clipped fish observed in September. The percentage of inspected carcasses that were adipose fin clipped decreased steadily from September (95 percent confidence interval 14.3 percent to 18.4 percent) through December (95 percent confidence interval 0 percent to 5.3 percent) (Figures A2 through A5). Sample sizes were smallest in December.

In the HFC, sample sizes were relatively small in September, but the corresponding percentage of adipose fin-clipped carcasses was the highest (Figure A-2). In October, sample sizes were high, but the corresponding percentage of adipose fin-clipped carcasses was relatively low (Figure A-3). In November, sample sizes were similar to those in October, but only one adipose fin-clipped carcass was detected (Figure A-4). In December, sample sizes were very small, and no adipose fin-clipped carcasses were detected (Figure A-4).

The percentage of inspected carcasses having a clipped adipose fin in 2002 presented by survey period, section/unit, and survey reach are shown in Figure A-6. Overall, the percentage of inspected carcasses that had a clipped adipose fin was higher in the LFC than in the HFC. In the LFC over the entire survey period, 9.0 percent of inspected carcasses were adipose fin clipped (95 percent confidence interval 8.2 to 9.8 percent). In the HFC over the entire survey period, 2.8 percent of inspected carcasses were adipose fin-clipped (95 percent confidence interval 1.9 to 3.9 percent). Results for the study area (LFC + HFC) over the entire survey period show that 7.9 percent of inspected carcasses were adipose fin-clipped (95 percent confidence interval 7.2 to 8.6 percent).

Most of the information acquired from decoding the CWTs from the 2002 survey is located in Tables 5.5-1 and 5.5-2. The heads from 439 carcasses having a clipped adipose fin were processed, and 350 (80.8 percent) contained a CWT (Table 5.5-1). Twelve of the salmon heads containing a CWT were not processed. Most of the processed carcasses were determined to have originated from Feather River stock (96.6 percent), and were released from the FRFH or by other hatcheries. The 2002 CWT sample consisted of 206 (60.9 percent) salmon that were released as fall-run Chinook salmon, and 132 (39.1 percent) that were released as spring-run Chinook salmon (Table 5.5-2). The greatest percentage (60.2 percent) of carcasses that were released as fall-run Chinook salmon were recovered during weeks 5 through 7

(September 30 through October 17). The greatest percentage (53 percent) of carcasses that were released as spring-run Chinook salmon were recovered during weeks 3 and 4 (September 16 through September 26). Overlap in carcass recoveries between fall-run and spring-run Chinook salmon occurred during week 1 through week 7 (September 3 through October 17), and was most significant during weeks 4 through 6 (September 23 through October 10). The greatest percentage of recovered carcasses that were released as fall-run Chinook salmon were determined to be 3 (42.7 percent) and 4 years old (48.1 percent). The greatest percentage of recovered carcasses that were released as spring-run Chinook salmon were determined to be 3 (18.2 percent) and 4 (74.2 percent) years old.

Table 5.5-1. Results from decoding the CWT collected during the 2002 CWT survey in the lower Feather River. The number of CWTs detected, the percentage of the total number of CWTs detected, and the assumed race (based on release data) of each salmon containing a CWT, by survey week, is shown.

	Fall-Run		Spring-Run	
Week	**Tags**	**%**	**Tags**	**%**
1	2	1	6	4.55
2	10	4.9	15	11.36
3	17	8.3	28	21.21
4	27	13.1	42	31.82
5	37	18	16	12.12
6	53	25.7	21	15.91
7	34	17	4	3.03
8	13	6.3		
9	8	3.9		
10	2	1		
11	1	0.5		
12	2	1		
13				
14				
15				
Total	**206**	**100**	**132**	**100**

Table 5.5-2. Run and age composition of the CWT sample collected during the 2002 CWT survey in the lower Feather River.

Age	Fall-Run		Spring-Run		Total	
	Tags	**%**	**Tags**	**%**	**Tags**	**%**
1	0	0	0	0	0	0
2	17	8.6	8	6.1	25	7.4
3	88	42.7	24	18.2	112	33.1
4	99	48.1	98	74.2	197	58.3
5	2	1	2	1.5	4	1.2
Total	**206**	**100**	**132**	**100**	**338**	**100**

The results from the 2003 CWT survey are shown in Table 5.4-4. The combined results for the LFC and the HFC show that 6,046 Chinook salmon carcasses were inspected for a clipped adipose fin. Of these, 411 carcasses had a clipped adipose fin, and 5,635 carcasses had an intact adipose fin. In the LFC, 4,502 carcasses were inspected for a clipped adipose fin. Of these, 379 carcasses had a clipped adipose fin, and 4,123 carcasses had an intact adipose fin. In the HFC, 1,544 carcasses were inspected for a clipped adipose fin. Of these, 32 carcasses had a clipped adipose fin, and 1,512 carcasses had an intact adipose fin. The temporal (month) and spatial (survey reach) distribution of the calculated percentage of inspected Chinook salmon carcasses having a clipped adipose fin, 95 percent confidence intervals, and sample sizes are shown in Figure 5.5-4. The percentage of inspected carcasses having a clipped adipose fin was highest in September (13.1 percent in the LFC, and 10.5 percent in the HFC), and then decreased steadily through December, although sample sizes were too small in December to provide precise calculations. The spatial distribution for salmon of known hatchery origin may be best reflected in October because of the larger sample sizes, and corresponding tight confidence intervals. The spatial distribution for salmon of known hatchery origin for the entire survey period is similar to the distribution in October, with the LFC having a higher percentage of inspected carcasses displaying a clipped adipose fin (approximately 8 percent in the LFC, and 2 percent in the HFC).

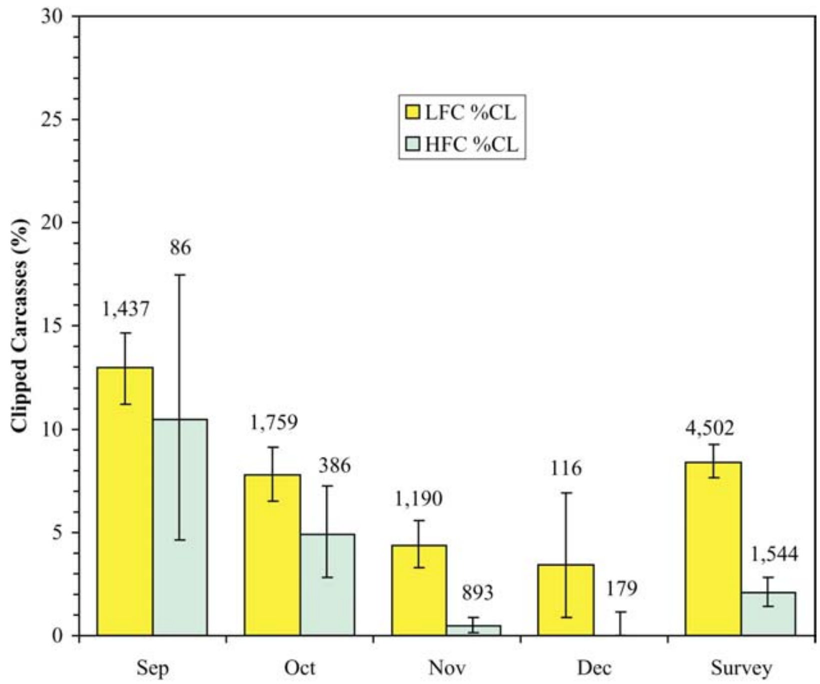


Figure 5.5-4. Percentage of carcasses having a clipped adipose fin, by survey month and reach, during the 2003 CWT survey in the lower Feather River.
Note: Error bars indicate the 95% confidence intervals, and the numbers represent sample sizes.

5.6 DISTRIBUTION OF CHINOOK SALMON CARCASS COUNTS

The temporal and spatial distributions of Chinook salmon carcass count totals, by survey week and reach, for the 2002 carcass survey data are shown in Figure 5.6-1. The majority of carcasses were detected in the LFC (81.1 percent out of a total of 47,160). The distribution of weekly carcass counts differed between reaches. The distribution in the LFC was relatively symmetrical. The highest carcass counts occurred from week 7 through week 9 (October 14 - 31), with week 8 (October 21 - 25) representing the peak. The distribution in the HFC was asymmetrical with the highest carcass counts occurring from week 11 through week 12 (November 11 - 21).

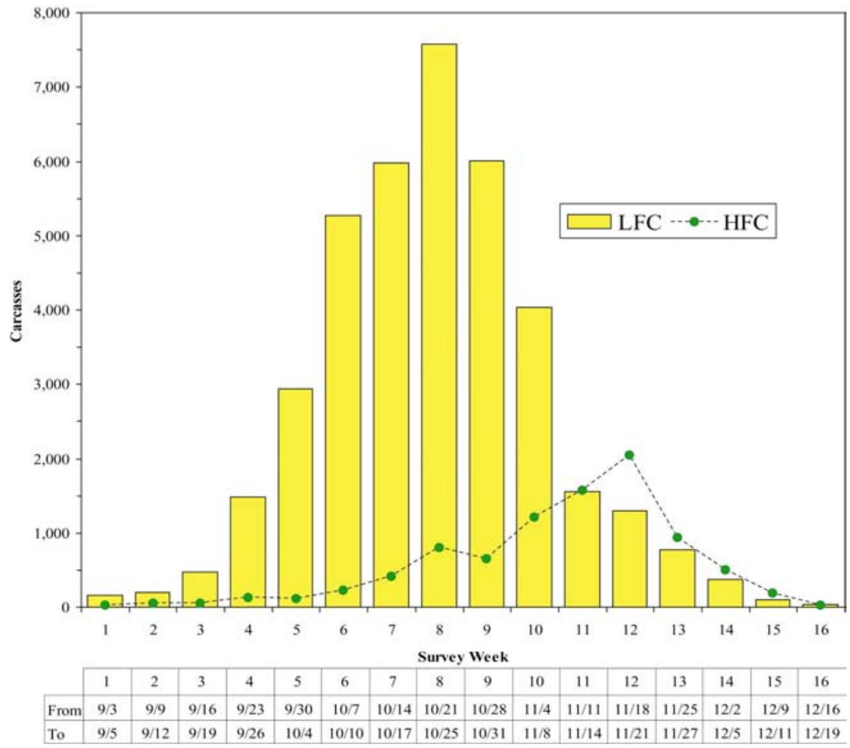


Figure 5.6-1. Carcass count totals, by survey week and reach, from the 2002 carcass survey in the lower Feather River.

The size (acres and ft^2) of each survey section/unit for the 2002 Chinook salmon carcass survey is shown in Table 5.6-1. Carcass densities by month, section/unit, and reach are displayed in Figures A-7 through A-10 . In September, the highest salmon carcass densities (9.1 to 110 carcasses/ acre) in the LFC occurred near the hatchery (section 1-10), slightly downstream of the Hwy. 162 bridge (sections 11-14), and between Robinson Riffle and Eye Riffle (sections 16-21) (Figure A-7) . In September, salmon carcass densities remained low throughout the HFC (<2 carcasses/acre). In October, salmon carcass densities in the LFC increased to 110 carcasses/acre for most of the sections/units, and in the HFC carcass densities ranged from 2.1 to 35/acre (Figure A-8). In November, carcass densities decreased in the LFC but, for all sections, remained relatively high (Figure A-9). The opposite occurred in the HFC. Salmon carcass densities increased in many sections of the HFC during November, with 35.1 to 110 carcasses/acre found in sections 25 and 36. In December, carcass densities dropped throughout the study area, with densities of 1 to 9/carcasses/acre in both reaches (Figure A-10). Overall, salmon carcass densities were higher in the LFC than in the HFC. In the LFC, highest densities occurred during October. In the HFC, highest densities occurred in November.

Table 5.6-1. The size (acres and ft^2) of each survey section/unit sampled in the lower Feather River during the 2002 Chinook salmon carcass survey.

Low Flow Channel			High Flow Channel		
	Area			Area	
Section	(Acres)	(ft^2)	Section	(Acres)	(ft^2)
1	5.75	250,375	24	8.41	366,319
2	1.07	46,717	25	7.57	329,923
3	2.31	100,757	26	10.70	466,283
4	2.17	94,436	27	10.49	457,067
5	0.44	19,186	28	12.93	563,349
6	5.23	227,804	29	13.89	605,081
7	0.35	15,131	30	10.38	452,205
8	5.53	240,675	31	10.62	462,813
9	7.16	311,743	32	N/E	
10	8.93	389,129	33	13.76	599,457
11	13.26	577,524	34	6.15	267,898
12	6.37	277,336	35	10.97	477,919
13	13.51	588,306	36	11.89	517,867
14	7.05	307,153	37	18.74	816,101
15	20.81	906,682	38	13.24	576,687
16	16.79	731,395	39	16.11	701,683
17	7.95	346,212	40	11.93	519,789
18	4.98	216,713	41	16.21	705,989
19	9.51	414,339	42	14.60	636,128
20	N/E		43	14.64	637,565
21	5.76	250,864	44	19.24	837,933
22	12.04	524,310	45	14.61	636,511
23	10.86	472,887	46	23.06	1,004,573
TOTAL	167.81	7,309,675	TOTAL	290.15	12,639,141

Carcass count totals were used to calculate the cumulative distribution of carcass counts, by study reach and survey day, to graphically explore potential relationships between the timing of spawning and mean daily water temperature (ºC). Water temperature data were available only for 2002. To smooth the percent cumulative distribution of carcass counts, the observed percentages were fitted to sigmoidal curves using non-linear regression (minimum least-squares). The LFC percent cumulative distribution (Y%) was fitted to a Logistic curve because the LFC distribution was considerably more symmetrical than the HFC distribution. The mathematical expression of this curve is:

$$Y\% = \frac{100}{1+\exp\left(8.8405-0.1099\times D\right)}.$$

where D is a continuous variable that indicates time as number of days counted from August 1, 2002 (e.g., for September 3, 2002 D=34, and for December 19, 2002 D=141.). The asymmetry present in the HFC carcass distribution was best modeled by a Negative Extreme Value curve with the following mathematical expression:

$$Y\% = 100\times\left(1-\exp\left(-\exp\left(-8.3692+0.0761\times D\right)\right)\right).$$

The Negative Extreme Value curve produced the smallest residual sum of squares (RSS=0.0468) among similar 2-parameter sigmoidal curves (e.g., RSS=0.0880 for a Logistic curve, and RSS=0.2015 for a Gompertz curve). The sigmoidal curves for both reaches, associated mean daily water temperatures, and 90 percent confidence intervals are displayed in Figure 5.6-2.

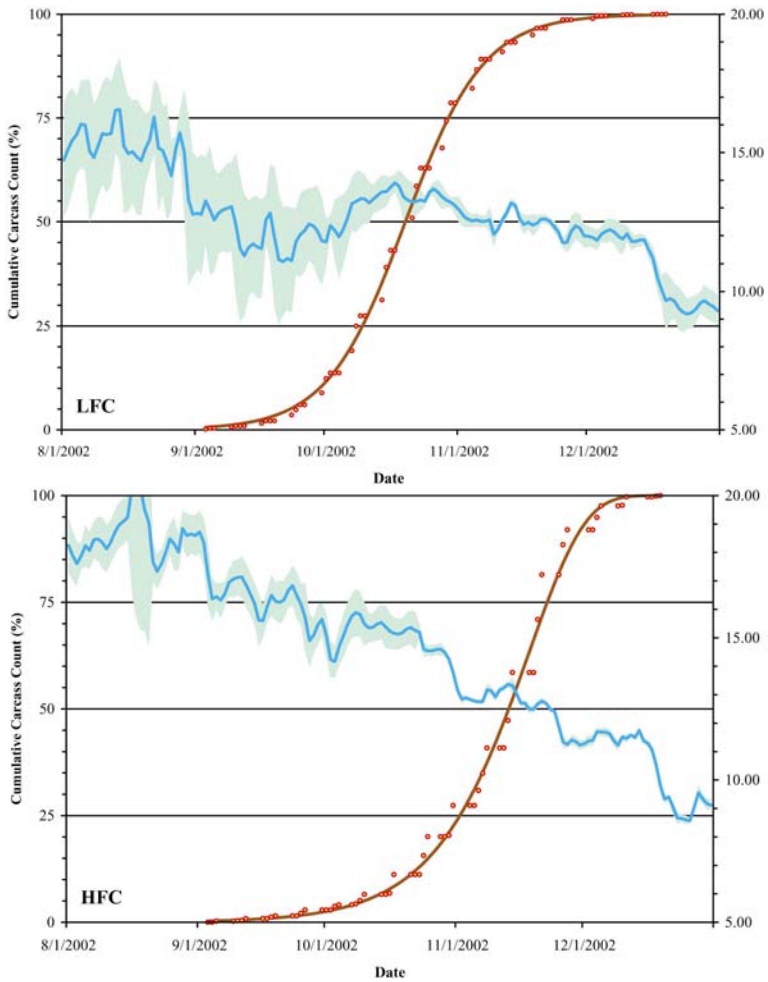


Figure 5.6-2. Daily cumulative carcass counts (%), average daily water temperatures (ºC), and 90% confidence intervals (shaded area) LFC (top) and the HFC (bottom) of the lower Feather River during the 2002 carcass survey. Observed daily cumulative percentages (circles) were fitted to sigmoidal curves.

In the LFC, mean daily water temperatures were negatively correlated with time. The trend is expressed by the following regression equation:

$$WT_{LFC} = 14.9728 - 0.0282 \text{ x } D \quad (r^2 = 0.553,\ p < 0.001).$$

The 90 percent confidence intervals in mean daily water temperatures in the LFC were wide due to high variation among water temperature data loggers. However, during most of the carcass survey period, mean daily water temperatures in the LFC ranged from 48.2^{o}F (9^{o}C) to 59^{o}F (15^{o}C). In the HFC, mean daily water temperatures were also negatively correlated with time. The trend is expressed by the following regression equation:

$$WT_{HFC} = 19.6274 - 0.0654 \text{ x D } (r^2 = 0.949, p < 0.001).$$

The negative correlation between water temperature and time was stronger in the HFC than in the LFC, as noted by a coefficient of determination value in the HFC. The 90 percent confidence intervals for mean daily water temperatures in the HFC were tighter than those for the mean daily water temperatures in the LFC. Mean daily water temperatures in the HFC ranged from 48.2°F (9°C) to 66.2°F (19°C). In the LFC and the HFC, approximately 100 percent and 90 percent, respectively, of the total cumulative carcass distributions occurred when mean daily water temperatures were below 59°F (15°C).

5.7 DISTRIBUTION OF CHINOOK SALMON CARCASS LENGTHS

The length-frequency distribution, by reach and sex, for the 2000 Chinook salmon carcass survey is shown in Figure 5.7-1. A total of 3,936 female and 2,447 male carcasses were measured FL (cm) during the survey period. In both reaches, the length-frequency distribution of male carcasses showed wider ranges than did female carcasses. The length-frequency distribution showed that a larger percentage of male carcasses were smaller than 25.6 in (65 cm) FL and greater than 39.4 in (100 cm) FL. In the LFC, male carcass lengths ranged from 13.4 in (34 cm) FL to 47.2 in (120 cm) FL, and female carcass lengths ranged from 19.3 in (49 cm) FL to 42.1 in (107 cm) FL. In the HFC, male carcass lengths ranged from 15.7 in (40 cm) FL to 45.7 in (116 cm) FL, and female carcass lengths ranged from 21.7 in (55 cm) FL to 39.4 in (100 cm) FL.

The length-frequency distribution, by reach and sex, for the 2001 Chinook salmon carcass survey is shown in Figure 5.7-2. A total of 1,573 female and 3,820 male carcasses were measured FL (cm) during the survey period. In both reaches, the length-frequency distribution of male carcasses showed wider ranges than did female carcasses. The length-frequency distribution showed that a larger percentage of male carcasses were smaller than 25.6 in (65 cm) FL, and greater than 39.4 in (100 cm) FL. In the LFC, male carcass lengths ranged from 15.4 in (39 cm) FL to 49.2 in (125 cm) FL, and female carcass lengths ranged from 9.8 in (25 cm) FL to 43.3 in (110 cm) FL. In the HFC, male carcass lengths ranged from 13.4 in (34 cm) FL to 45.3 in (115 cm) FL, and female carcass lengths ranged from 15.8 in (40 cm) FL to 45.3 in (115 cm) FL.

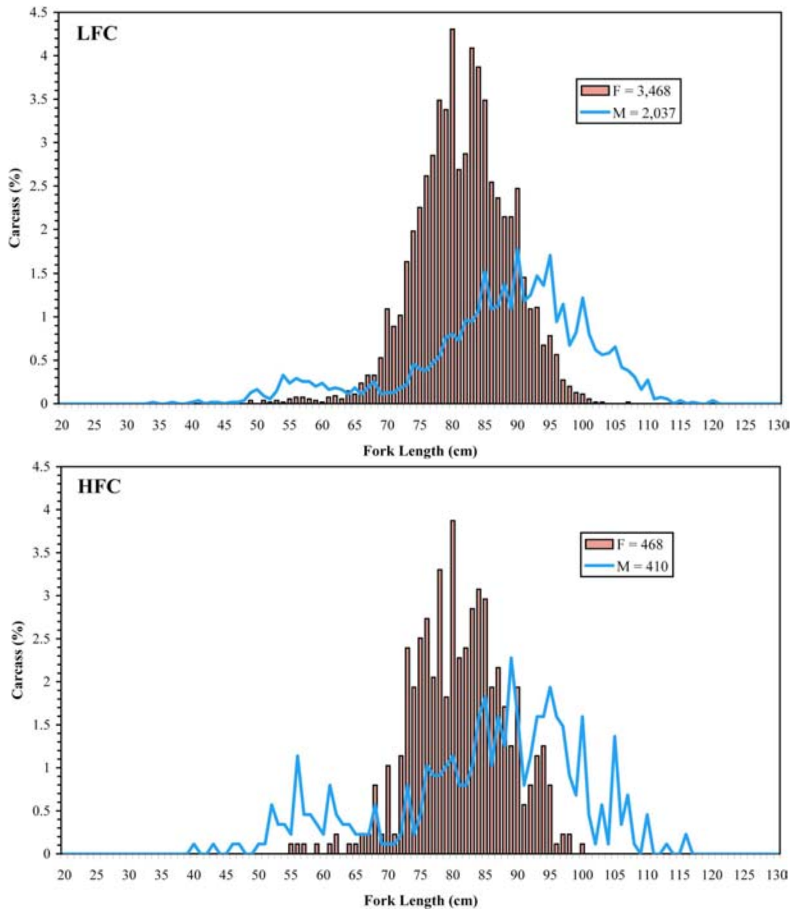


Figure 5.7-1. Length-frequency distributions for male (M) and female (F) carcasses sampled in the LFC (top) and HFC (bottom) of the lower Feather River during the 2000 carcass survey. Percentages were calculated over the total number of carcasses (M + F) sampled in each survey reach.

The length-frequency distribution, by reach and sex, for the 2002 Chinook salmon carcass survey is shown in Figure 5.7-3. A total of 3,524 female and 2,300 male carcasses were measured FL (cm) during the survey period. In both reaches, the length-frequency distribution of male carcasses showed wider ranges than did female carcasses. The length-frequency distribution showed that a larger percentage of male carcasses were smaller than 25.6 in (65 cm) FL and greater than 39.4 in (100 cm) FL. In the LFC, male carcass lengths ranged from 16.9 in (43 cm) FL to 50.4 in (128 cm) FL, and female carcass lengths ranged from 20.5 in (52 cm) FL to 43.7 in (111 cm) FL. In the HFC, male carcass lengths ranged from 16.5 in (42 cm) FL to 47.2 in (120 cm) FL, and female carcass lengths ranged from 20.9 in (53 cm) FL to 45.3 in (115 cm) FL.

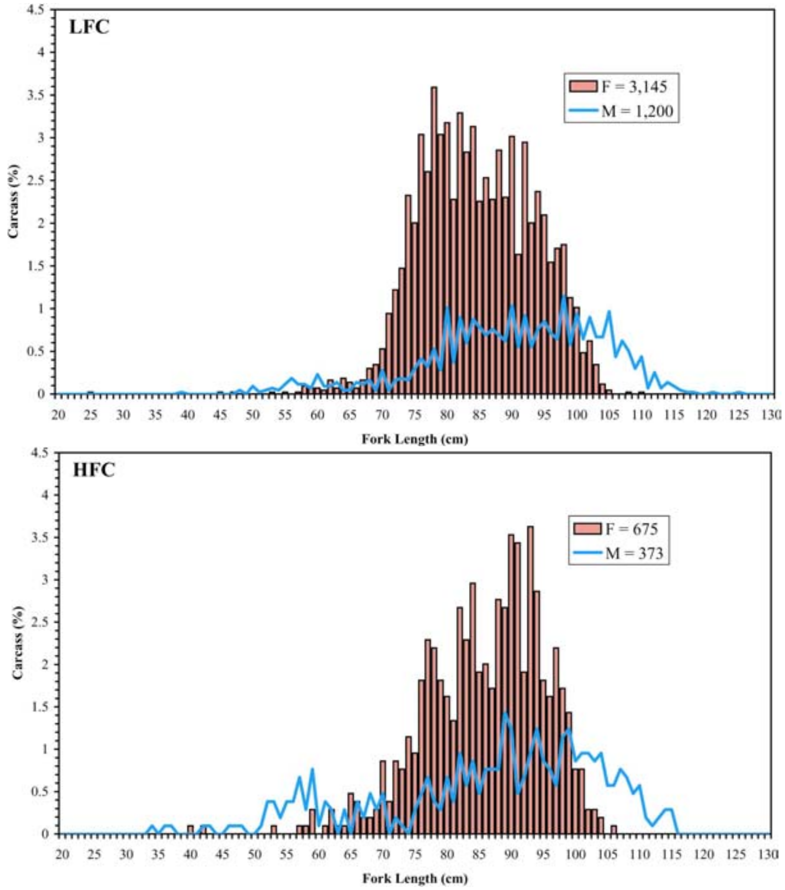


Figure 5.7-2. Length-frequency distributions for male (M) and female (F) carcasses sampled in the LFC (top) and the HFC (bottom) of the lower Feather River during the 2001 carcass survey. Percentages were calculated over the total number of carcasses (M + F) sampled in each survey reach.

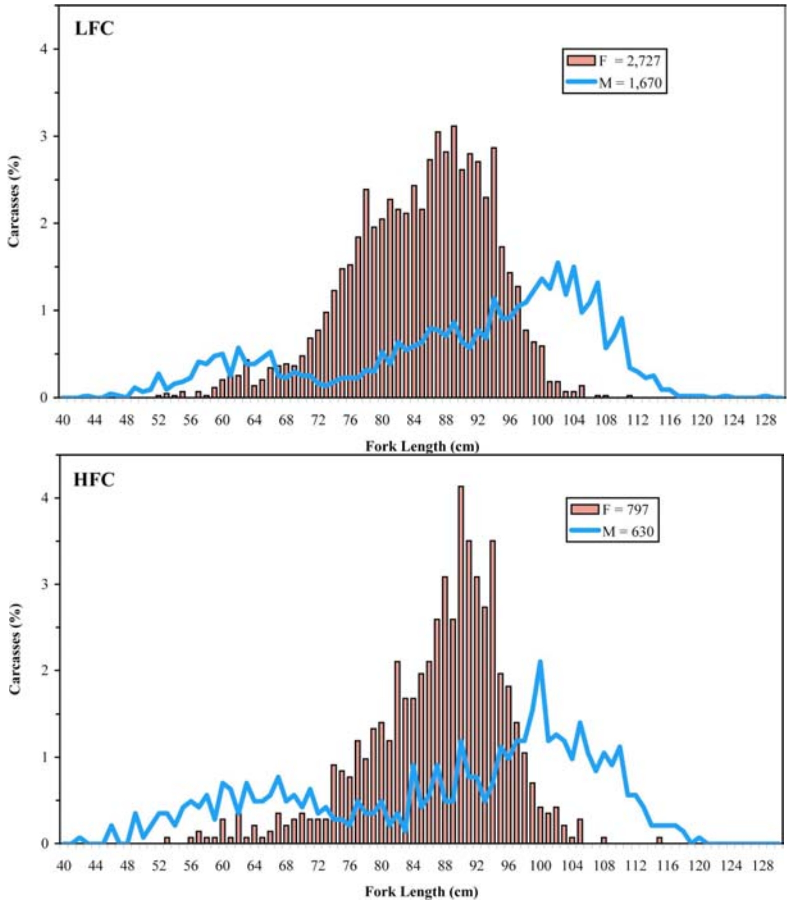


Figure 5.7-3. Length-frequency distributions for male (M) and female (F) carcasses sampled in the LFC (top) and the HFC (bottom) of the lower Feather River during the 2002 carcass survey. Percentages were calculated over the total number of carcasses (M + F) sampled in each survey reach.

Box plots for the 2002 Chinook salmon carcass survey, by sex and survey month, are shown in Figure 5.7-4. Mean monthly lengths for male and female carcasses ranged from approximately 33.9 in (86 cm) FL to 36.2 in (92 cm) FL, and approximately 33.1 in (84 cm) FL to 34.6 in (88 cm) FL, respectively. The highest mean monthly length for female carcasses occurred in the HFC during October. The highest mean monthly length for male carcasses occurred in the LFC in November/December. As mentioned previously, male carcass length showed greater variation than female carcass length. Results from the box plot do not elucidate statistical differences in mean lengths. T-tests were used to test for differences in mean carcass length between reaches, by sex and by sample month. The results of the t-tests (Table 5.7-1) showed that the mean length of female carcasses collected in October, and November/December differed between reaches ($p<0.0001$; HFC > LFC for both tests), and the mean length of female carcasses collected in September were not statistically different between reaches ($p>0.05$). The mean length of male carcasses collected in November/December differed between reaches ($p<0.0001$; LFC > HFC), and the mean length of male carcasses collected in September and October were not statistically different between reaches ($p>0.05$). For additional analyses concerning carcass length distribution, see Section 2.4.

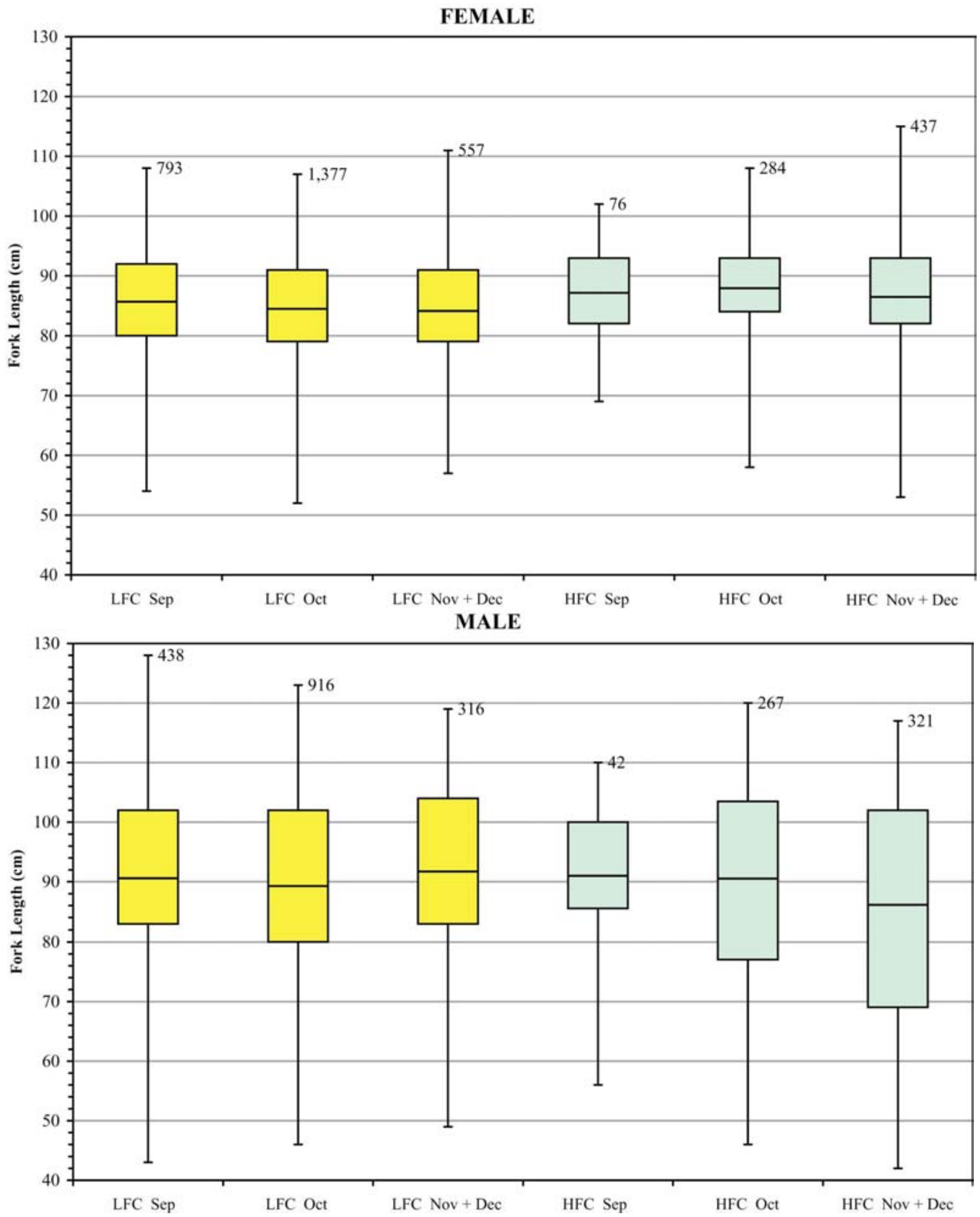


Figure 5.7-4. Box plots of the monthly length distributions of male and female carcasses sampled in the lower Feather River during the 2002 carcass survey. The lower and upper borders in each box indicate the 25th and 75th percentiles. The middle line in each box marks average lengths, the bars indicate the minimum and maximum lengths, and the numbers represent sample sizes.

Table 5.7-1. Results of two sample t-tests to test for differences between the monthly mean lengths of male and female carcass collected in the lower Feather River during the 2002 carcass survey.

Categories	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2
Sex	F	F	F	F	F	F
Month	Sep	Sep	Oct	Oct	Nov + Dec	Nov + Dec
Reach	LFC	HFC	LFC	HFC	LFC	HFC
Means (μ_1, μ_2)	85.7	87.2	84.5	87.9	84.1	86.5
Variances	71.4	54.3	78.8	75.7	82.6	76.6
Sample size	793	76	1,377	284	557	437
Pooled Variance	69.9		78.3		80	
Degrees of freedom	867		1,659		992	
t Statistic	-1.472		-5.964		-4.146	
P(T<=t)	0.141		1.50E-09		1.80E-05	
Conclude	$\mu_1 = \mu_2$		$\mu_1 < \mu_2$		$\mu_1 < \mu_2$	
Categories	**Group 1**	**Group 2**	**Group 1**	**Group 2**	**Group 1**	**Group 2**
Sex	M	M	M	M	M	M
Month	Sep	Sep	Oct	Oct	Nov + Dec	Nov + Dec
Reach	LFC	HFC	LFC	HFC	LFC	HFC
Means (μ_1, μ_2)	90.6	91	89.3	90.5	91.7	86.1
Variances	239.2	205.8	278.7	312.2	290.6	360.9
Sample size	438	42	916	267	316	321
Pooled Variance	236.4		286.2			
Degrees of freedom	478		1,181		630	
t Statistic	-0.165		-1.07		3.91	
P(T<=t)	0.869		0.285		5.10E-05	
Conclude	$\mu_1 = \mu_2$		$\mu_1 = \mu_2$		$\mu_1 > \mu_2$	

The length-frequency distribution, by reach and sex, for the 2003 Chinook salmon carcass survey is shown in Figure 5.7-5 . A total of 4,035 female and 2,039 male carcasses were measured FL (cm) during the survey period. In both reaches, the length-frequency distribution of male carcasses showed wider ranges than did female carcasses. The length-frequency distribution showed that a larger percentage of male carcasses were smaller than 25.6 in (65 cm) FL and greater than 39.4 in (100 cm) FL. In the LFC, male carcass lengths ranged from 15.7 in (40 cm) FL to 45.3 in (115 cm) FL, and female carcass lengths ranged from 18.9 in (48 cm) FL to 40.2 in (102 cm) FL. In the HFC, male carcass lengths ranged from 17.3 in (44 cm) FL to 47.2 in (120 cm) FL, and female carcass lengths ranged from 19.7 in (50 cm) FL to 42.1 in (107 cm) FL.

5.8 SEX RATIOS

In the 2000 Chinook salmon carcass survey, all carcasses detected were sexed, with 23,251 carcasses classified as male and 26,877 classified as female. The total number of sexed carcasses included grilse. Sex ratios are expressed as the percentage of the carcass count total that were females. In the LFC and the HFC, female carcasses accounted for 54.3 percent and 50.4 percent of the carcass count total, respectively (Table 5.8-1). Standard errors and 95 percent confidence intervals were calculated using 1,000 bootstrap simulations per case to allow for a comparison of the estimates between reaches. Each bootstrap simulation assumed that in each reach, females were distributed as a binomial distribution, with parameters equal to the estimated female proportion and the observed sample sizes. Standard errors were low for both reaches, but slightly higher in the HFC. The 95 percent confidence intervals were narrow for both reaches.

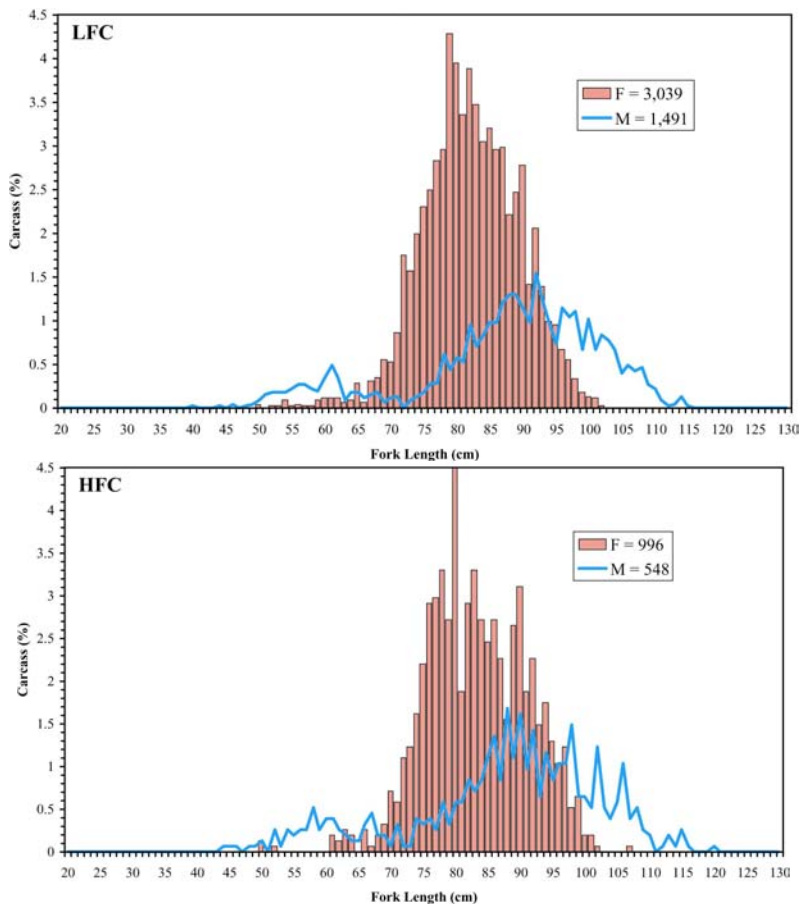


Figure 5.7-5. Length-frequency distributions for male (M) and female (F) carcasses sampled in the LFC (top) and HFC (bottom) of the lower Feather River during the 2002 carcass survey. Percentages were calculated over the total number of carcasses (M + F) sampled in each survey reach.

Table 5.8-1. The percentage of carcasses that were female, standard errors, and 95% confidence intervals for carcasses collected in the lower Feather River during the 2000 carcass survey.

	LFC	HFC
Estimate	54.25	50.38
Stand. Error	0.23	0.54
95% CI	(53.80 - 54.69)	(49.34 - 51.40)

In the 2001 Chinook salmon carcass survey, not all carcasses detected were sexed. A sub-sample of 5,395 carcasses was measured using FL (cm). Of these, 3,820 carcasses were male, 1,573 carcasses were female, and 2 carcasses were not sexed. In this sub-sample, grilse were sexed. In the LFC and the HFC, female carcasses accounted for 72.4 percent and 64.4 percent of the carcass count total, respectively (Table 5.8-2). Standard errors and 95 percent confidence intervals were calculated using 1,000 bootstrap simulations per case to allow for a comparison of the estimates between reaches. Each bootstrap simulation assumed that in each reach, females were distributed as a binomial distribution, with parameters equal to the estimated female proportion and the observed sample sizes. Standard errors were low for both reaches, but slightly higher in the HFC. The 95 percent confidence intervals were narrow for both reaches.

Table 5.8-2. The percentage of carcasses that were female, standard errors, and 95% confidence intervals for carcasses collected in the lower Feather River during the 2001 carcass survey.

	LFC	HFC
Estimate	72.38	64.41
Stand. Error	0.70	1049
95% CI	(71.07 – 73.74)	(62.02 – 67.84)

In the 2002 Chinook salmon carcass survey, not all carcasses detected were sexed. Of the 47,160 carcasses detected during the survey period, a random sub-sample of 43,806 carcasses was classified as male (16,789), female (23,108), or grilse (3,909). In this sub-sample, grilse were not sexed. A sub-sample of 5,829 carcasses was measured using FL (cm). Of these, 2,300 carcasses were male, 3,524 carcasses were female, and 5 carcasses were not sexed. In this sub-sample, grilse were sexed. The proportion of females in a population (also referred to as sex ratio) is typically estimated by dividing the number of female carcasses detected by the total number of carcasses detected (both sexes). Two methods were used to calculate the estimated proportion of females from the 2002 carcass survey data. The first sub-sample of 43,806 carcasses was used to determine the sex ratio for each reach. In the LFC, 12,836 male carcasses and 19,354 female carcasses were used to calculate the proportion of female carcasses (P_{FLFC}) as:

$$P_{FLFC} = \frac{19{,}354}{12{,}836 + 19{,}354} = 0.6012 .$$

In the HFC, 3,953 male carcasses and 3,754 female carcasses were used to calculate the proportion of female carcasses (P_{FHFC}) as:

$$P_{FHFC} = \frac{3{,}754}{3{,}953 + 3{,}754} = 0.4871 .$$

Under this method, sample sizes were large and estimates may be more reflective of the true population parameters. However, these estimates may be biased. A total of 3,909 grilse (8.9 percent of the total) were not included in these calculations. The sex ratio of the grilse population, if different from the sex ratio of the adult population, could influence estimates. The second method that was used to calculate the estimated proportion of females from the 2002 carcass survey data utilized the second sub-sample of 5,829. In the LFC, 1,670 male carcasses and 2,727 female carcasses were used to calculate the proportion of female carcasses (P_{FLFC}) as:

$$P_{FLFC} = \frac{2{,}727}{1{,}670 + 2{,}727} = 0.6202 .$$

In the HFC, 630 male carcasses and 797 female carcasses were used to calculate the proportion of female carcasses (P_{FHFC}) as:

$$P_{FHFC} = \frac{797}{630 + 797} = 0.5585 .$$

The estimates derived from this second method are not biased, provided samples were collected randomly, because both adult and grilse sex ratios are included in calculations. However, these estimates may have lower precision due to smaller sample size.

The estimated sex ratios, standard errors, and 95 percent confidence intervals for each reach (LFC, HFC) are shown in Table 5.8-3. Sex ratio estimates in the LFC for each approach were 0.60 and 0.62. Sex ratio estimates in the HFC for each approach were 0.49 and 0.56. Female carcasses were detected at higher proportions in the LFC. Standard errors and confidence intervals were similar between reaches and approaches.

Table 5.8-3. The estimated sex ratios (proportion that were females), standard errors, and 95% confidence intervals for carcasses collected in the lower Feather River during the 2002 carcass survey.

Approach		LFC	HFC
1	Estimate (*PF*)	0.6012	0.4871
	Stand. Error	0.0312	0.0388
	95% CI	(0.5528 - 0.6427)	(0.4080 - 0.5367)
2	Estimate	0.6202	0.5585
	Stand. Error	0.0351	0.0381
	95% CI	(0.5777 - 0.6805)	(0.5067 - 0.6174)

The spatial distributions of the sex ratios are shown in Figure A-11. The percentage of sampled females was determined for each section/unit by dividing the number of female carcasses detected by the total number of carcasses detected. In general, females comprised a larger percentage of the total carcass count in the LFC than in the HFC. In general, both reaches showed a negative correlation between female percentage and distance downstream.

In the 2003 Chinook salmon carcass survey, not all carcasses detected were sexed. Of the 39,709 carcasses detected during the survey period, a random sub-sample of 31,352 carcasses was classified as male (11,904), female (17,945), or grilse (1,503). In this sub-sample, grilse were not sexed. A sub-sample of 6,087 carcasses was measured using FL (cm). Of these, 2,039 carcasses were male, 4,035 carcasses were female, and 13 carcasses were not sexed. In this sub-sample, grilse were sexed. In the LFC and the HFC, female carcasses accounted for 67.1 percent and 64.5 percent of the carcass count total, respectively (Table 5.8-4). Standard errors and 95 percent confidence intervals were calculated using 1,000 bootstrap simulations per case to allow for a comparison of the estimates between reaches. Each bootstrap simulation assumed that in each reach, females were distributed as a binomial distribution, with parameters equal to the estimated female proportion and the observed sample sizes.

Standard errors were low for both reaches, but slightly higher in the HFC. The 95 percent confidence intervals were narrow for both reaches.

Table 5.8-4. The percentage of carcasses that were female, standard errors, and 95% confidence intervals for carcasses collected in the lower Feather River during the 2003 carcass survey.

	LFC	HFC
Estimate	67.09	64.51
Stand. Error	0.73	0.12
95% CI	(65.67 – 68.59)	(62.11 – 66.90)

5.9 SPAWNING ESCAPEMENT ESTIMATES

In the LFC, the 2000, 2001, 2002, and 2003 Schaefer variables, calculated using the carcass survey data, used to estimate spawning escapement totals for Chinook salmon in the lower Feather River are shown in Table 5.9-1, Table 5.9-2, Table 5.9-3, and Table 5.9-4, respectively. In the LFC, the yearly ($\hat{N}$) and weekly ($\hat{N}_j$) Schaefer spawning escapement estimates for the 2000, 2001, 2002, and 2003 carcass survey are shown in Table 5.9-5, Table 5.9-6, Table 5.9-7, and Table 5.9-8, respectively. Although both $\hat{N}_j$ and $\hat{N}_i$ represent weekly estimates, $\hat{N}_j$ was used to describe weekly spawning escapement estimates because estimates from this variable are statistically stronger.

In 2000, weekly spawning escapement estimates ranged from 355 (week 2) to 16,930 (week 7), estimates were highest between week 6 and week 10, and the highest estimate occurred during week 7. The greatest positive difference in estimates between adjacent survey weeks occurred between week 5 and week 6 when estimates increased by 6,109. The greatest negative difference in estimates between adjacent survey weeks occurred between week 8 and week 9 when estimates decreased by 6,948. Weekly spawning escapement estimates steadily increased through week 7, then steadily decreased through week 15. The yearly spawning escapement estimate in the LFC during 2000 was 73, 416.

In 2001, weekly spawning escapement estimates ranged from 1,089 (week 2) to 18,566 (week 8), estimates were highest between week 5 and week 10, and the highest estimate occurred during week 8. The greatest positive difference in estimates between adjacent survey weeks occurred between week 4 and week 5 when estimates increased by 7,386. The greatest negative difference in estimates between adjacent survey weeks occurred between week 10 and week 11 when estimates decreased by 4,664. Weekly spawning escapement estimates steadily increased through week 8, then steadily decreased through week 14. The yearly spawning escapement estimate in the LFC during 2001 was 117,072.

Table 5.9-1. Summary of the Schaefer variables used to estimate the 2000 spawning escapement in the LFC of the lower Feather River.

Week	Recovery by Week of Tagging *i* ($R_{i,j}$)																
j\i	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	R_j	C_j	C_j/R_j
2	18															18	174	9.67
3	5	29														34	348	10.2
4		14	77													91	1,155	12.7
5	1	1	11	195												208	3,203	15.4
6			5	37	200											242	6,492	26.8
7			2	22	97	302										423	9,616	22.7
8				2	23	73	392									490	9,155	18.7
9			1	1	7	24	119	399								551	5,540	10.1
10			1		1	7	21	67	246							343	3,479	10.1
11							3	18	52	233						306	2,541	8.3
12							2	4	15	56	99					176	1,452	8.25
13					1			1	1	18	34	46				101	1,021	10.1
14										2	7	17	40			66	492	7.45
15								1			2	5	10	14		32	206	6.44
16																		
R_i	24	44	97	257	329	406	537	490	314	309	142	68	50	14		3,081	44,874	
T_i	49	76	198	472	609	700	905	734	570	514	271	133	111	33		5,375		
T_i/R_i	2	1.7	2	1.8	1.9	1.7	1.7	1.5	1.8	1.7	1.9	2	2.2	2.4				

Each cell contains the number of fresh carcasses tagged in tagging week ***i****, and recovered in recovery week j ($R_{i,j}$). T_i is the number of fresh carcasses observed and tagged in tagging week i. R_i is the total number of tags released in tagging week* i *that were recovered at the end of the carcass survey, and R_j is the number of tags recovered in recovery week* j. *C_j is the total number of carcasses counted in recovery week j. C_j includes the number of decayed carcasses observed and clipped, the number of fresh carcasses observed and tagged, the number of fresh carcasses observed and chopped, and the number of tagged carcasses recovered in week j.*

In 2002, weekly spawning escapement estimates ranged from 179 (week 16) to 15,111 (week 8), estimates were highest between week 6 and week 10, and the highest estimate occurred during week 8. The greatest positive difference in estimates between adjacent survey weeks occurred between week 5 and week 6 when estimates increased by 5,129. The greatest negative difference in estimates between adjacent survey weeks occurred between week 10 and week 11 when estimates decreased by 4,318. Weekly spawning escapement estimates increased steadily through week 8, then decreased steadily through week 16. The yearly spawning escapement estimate in the LFC during 2002 was 70,952.

In 2003, weekly spawning escapement estimates ranged from 597 (week 16) to 9,790 (week 8), estimates were highest between week 5 and week 10, and the highest estimate occurred during week 8. The greatest positive difference in estimates between adjacent survey weeks occurred between week 5 and week 6 when estimates increased by 3,457. The greatest negative difference in estimates between adjacent survey weeks occurred between week 8 and week 9 when estimates decreased by 2,871. Weekly spawning escapement estimates increased steadily through week 8, then decreased steadily through week 16. The yearly spawning escapement estimate in the LFC during 2003 was 58,468.

Table 5.9-2. Summary of the Schaefer variables used to estimate the 2001 spawning escapement in the LFC of the lower Feather River.

Week	**Recovery by Week of Tagging *i* (*R_{i,j}*)**																	
j\i	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	***R_j***	***C_j***	***C_j/R_j***
2	11															11	363	33
3	2	48														50	899	17.98
4		5	63													68	2,489	36.6
5		1	24	100												125	5,264	42.11
6		1	1	50	139											191	5,383	28.18
7			1	3	33	124										161	5,090	31.61
8			1		3	29	176									209	7,326	35.05
9						3	48	172								223	6,518	29.23
10	1						6	21	143							171	4,545	26.58
11							1	3	25	97						126	2,994	23.76
12							2			10	34					46	1,035	22.5
13										2	15	9				26	746	28.69
14										1	2	6	5			14	280	20
15																		
16																		
R_i	14	55	90	153	175	156	233	196	168	110	51	15	5			1,421	42,932	
T_i	42	125	241	406	501	505	562	533	494	310	236	57	26			4,038		
T_i/R_i	3	2.27	2.68	2.65	2.86	3.24	2.41	2.72	2.94	2.82	4.63	3.8	5.2					

Each cell contains the number of fresh carcasses tagged in tagging week i, and recovered in recovery week j ($R_{j,,j}$)*. Ti is the number of fresh carcasses observed and tagged in tagging week i.* R_j *is the total number of tags released in tagging week i that were recovered at the end of the carcass survey, and Rj is the number tags recovered in recovery week j. Cj is the total number of carcasses counted in recovery week j. Cj includes the number of decayed carcasses observed and clipped, the number of fresh carcasses observed and tagged, the number of fresh carcasses observed and chopped, and the number of tagged carcasses recovered in week j*

Table 5.9-3. Summary of the Schaefer variables used to estimate the 2002 spawning escapement in the LFC of the lower Feather River.

Week	**Recovery by Week of Tagging *i* (*R_{i,j}*)**																	
j\i	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	***R_j***	***C_j***	***C_j/R_j***
2	29															29	199	6.86
3	3	27														30	468	15.6
4	1	4	90													95	1,479	15.57
5	1		30	336												367	2,935	8
6			2	102	376											480	5,268	10.98
7			2	13	71	298										384	5,981	15.58
8				4	17	77	360									458	7,581	16.55
9					3	7	50	438								498	6,009	12.07
10					1		13	82	403							499	4,032	8.08
11							1	6	64	191						262	1,560	5.95
12								2	5	67	109					183	1,298	7.09
13										19	26	52				97	772	7.96
14								1			2	20	30			53	379	7.15
15												2	2	18		22	99	4.5
16														2	2	4	33	8.25
R_i	34	31	124	455	468	382	424	529	472	277	137	74	32	20	2	3,461	38,093	
T_i	73	85	247	845	963	873	818	976	929	659	269	208	83	57	16	7,101		
T_i/R_i	2.15	2.74	1.99	1.86	2.06	2.29	1.93	1.84	1.97	2.38	1.96	2.81	2.59	2.85	8			

Each cell contains the number of fresh carcasses tagged in tagging week **i***, and recovered in recovery week* j ($R_{i,j}$)*.* T_i *is the number of fresh carcasses observed and tagged in tagging week* i*.* R_i *is the total number of tags released in tagging week* i *that were recovered at the end of the carcass survey, and* R_j *is the number of tags recovered in recovery week* j*.* C_j *is the total number of carcasses counted in recovery week* j*.* C_j *includes the number of decayed carcasses observed and clipped, the number of fresh carcasses observed and tagged, the number of fresh carcasses observed and chopped, and the number of tagged carcasses recovered in week* j.

Table 5.9-4. Summary of the Schaefer variables used to estimate the 2003 spawning escapement in the LFC of the lower Feather River.

Week	**Recovery by Week of Tagging *i* ($R_{i,j}$)**																
j**i	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	R_j	C_j	C_j/R_j
2	47															47	349	7.43
3	11	51														62	785	12.66
4	1	10	111													122	1,573	12.89
5	1	4	23	185												213	2,976	13.97
6		1	7	33	222											263	4,577	17.40
7		1	3	4	40	337										385	4,952	12.86
8			4		14	98	381									497	5,297	10.66
9					1	13	75	347								436	3,832	8.79
10						3	15	99	324							441	2,911	6.60
11						3	2	16	61	206						288	1,942	6.74
12						1	1	1	11	46	145					205	1,570	7.66
13									2	16	56	139				213	1,194	5.61
14									1	3	7	31	66			108	500	4.63
15									2		2	8	26	13		51	273	5.35
16												3	3	2	2	10	106	10.60
R_i	60	67	148	222	277	455	474	463	401	271	210	181	95	15	2	3,341	32,837	
T_i	127	152	273	458	580	870	864	832	808	530	404	355	234	83	32	6,602		
T_i/R_i	2.12	2.27	1.84	2.06	2.09	1.91	1.82	1.80	2.01	1.96	1.92	1.96	2.46	5.53	16.00			

Each cell contains the number of fresh carcasses tagged in tagging week **i**, *and recovered in recovery week* j ($R_{i,j}$). T_i *is the number of fresh carcasses observed and tagged in tagging week* i. R_i *is the total number of tags released in tagging week* i *that were recovered at the end of the carcass survey, and* R_j *is the number of tags recovered in recovery week* j. C_j *is the total number of carcasses counted in recovery week* j. C_j *includes the number of decayed carcasses observed and clipped, the number of fresh carcasses observed and tagged, the number of fresh carcasses observed and chopped, and the number of tagged carcasses recovered in week* j.

Table 5.9-5. The 2000 spawning escapement estimates in the LFC of the lower Feather River calculated by the Schaefer (1951) mark-recovery method.

$$R_{i,j} \times \frac{T_i}{R_i} \times \frac{C_j}{R_j}$$

Week J \ i	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	$\hat{N}_j$
2	355															355
3	104	513														617
4	0	307	1,995													2,302
5	31	27	346	5,515												5,919
6	0	0	274	1,823	9,931											12,028
7	0	0	93	919	4,082	11,837										16,930
8	0	0	0	69	795	2,352	12,343									15,559
9	0	0	21	18	130	416	2,016	6,009								8,611
10	0	0	21	0	19	122	359	1,018	4,529							6,068
11	0	0	0	0	0	0	42	224	784	3,218						4,268
12	0	0	0	0	0	0	28	49	225	769	1,559					2,629
13	0	0	0	0	19	0	0	15	18	303	656	910				1,920
14	0	0	0	0	0	0	0	0	0	25	100	248	662			1,034
15	0	0	0	0	0	0	0	10	0	0	25	63	143	212		453
16																
$\hat{N}_i$	491	846	2,749	8,343	14,976	14,727	14,788	7,325	5,556	4,314	2,339	1,220	805	212		78,693
T_i	49	-76	-198	-472	-609	-700	-905	-734	-570	-514	-271	-133	-111	-33		-5,277
Estimated total spawning escapement $\hat{N}$ in the LFC																**73,416**

$\hat{N}_i$ is the estimated portion of the spawning escapement that is available for tagging in tagging week i, and $\hat{N}_j$ is the estimated portion of the spawning escapement that is available for recovery in recovery week j. The estimated total spawning escapement $\hat{N}$ is calculated as $\hat{N} = N_i - \sum_i T_i$, where T_i is the number of fresh carcasses observed and tagged in tagging week i. $\hat{N}_j$ was calculated as $\hat{N}_j = \sum_i \left(R_{i,j} \times \frac{T_i}{R_i} \times \frac{C_j}{R_j} \right)$.

Table 5.9-6. The 2001 spawning escapement estimates in the LFC of the lower Feather River calculated by the Schaefer (1951) mark-recovery method.

$$R_{i,j} \times \frac{T_i}{R_i} \times \frac{C_j}{R_j}$$

Week j \ i	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	$\hat{N}_j$
2	1,089															1,089
3	108	1,961														2,069
4	0	416	6,175													6,591
5	0	96	2,706	11,175												13,977
6	0	64	75	3,739	11,215											15,094
7	0	0	85	252	2,987	12,691										16,014
8	0	0	94	0	301	3,291	14,880									18,566
9	0	0	0	0	0	284	3,384	13,671								17,339
10	80	0	0	0	0	0	385	1,518	11,176							13,158
11	0	0	0	0	0	0	57	194	1,747	6,496						8,494
12	0	0	0	0	0	0	109	0	0	634	3,540					4,283
13	0	0	0	0	0	0	0	0	0	162	1,992	981				3,135
14	0	0	0	0	0	0	0	0	0	56	185	456	520			1,217
15																
16																
$\hat{N}_I$	1,277	2,537	9,135	15,166	14,503	16,265	18,815	15,383	12,923	7,348	5,717	1,437	520			121,026
T_i	42	-125	-241	-406	-501	-505	-562	-533	-494	-310	-236	-57	-26			-3,954
Estimated total spawning escapement $\hat{N}$ in the LFC																**117,072**

$\hat{N}_I$ is the estimated portion of the spawning escapement that is available for tagging in tagging week i, and $\hat{N}_j$ is the estimated portion of the spawning escapement that is available for recovery in recovery week j. The estimated total spawning escapement $\hat{N}$ is calculated as $\hat{N}=N_j - \sum_i T_i$, where T_i is the number of fresh carcasses observed and tagged in tagging week i. $\hat{N}_j$ was calculated as

$$\hat{N}_J = \sum_i \left(R_{i,j} \times \frac{T_i}{R_i} \times \frac{C_j}{R_j} \right).$$

Table 5.9-7. The 2002 spawning escapement estimates in the LFC of the lower Feather River calculated by the Schaefer (1951) mark-recovery method.

$R_{i,j} \times \frac{T_i}{R_i} \times \frac{C_j}{R_j}$																
Week *j* \ *i*	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	$\hat{N}_j$
2	427															427
3	100	1,155														1,255
4	33	171	2,791													2,995
5	17	0	478	4,990												5,485
6	0	0	44	2,079	8,491											10,614
7	0	0	62	376	2,276	10,607										13,321
8	0	0	0	123	579	2,913	11,496									15,111
9	0	0	0	0	74	193	1,164	9,751								11,182
10	0	0	0	0	17	0	203	1,222	6,409							7,851
11	0	0	0	0	0	0	11	66	750	2,706						3,533
12	0	0	0	0	0	0	0	26	70	1,131	1,518					2,745
13	0	0	0	0	0	0	0	0	0	360	406	1,163				1,929
14	0	0	0	0	0	0	0	13	0	0	28	402	556			1,000
15	0	0	0	0	0	0	0	0	0	0	0	25	23	231		279
16	0	0	0	0	0	0	0	0	0	0	0	0	0	47	132	179
$\hat{N}_I$	578	1,326	3,375	7,568	11,437	13,713	12,874	11,079	7,229	4,196	1,952	1,591	580	278	132	77,907
T_i	73	-85	-247	-845	-963	-873	-818	-976	-929	-659	-269	-208	-83	-57	-16	-6,955
Estimated total spawning escapement $\hat{N}$ in the LFC																**70,952**

$\hat{N}_I$ is the estimated portion of the spawning escapement that is available for tagging in tagging week i, and $\hat{N}_j$ is the estimated portion of the spawning escapement that is available for recovery in recovery week j. The estimated total spawning escapement $\hat{N}$ is calculated as $\hat{N} = N_j - \sum_i T_i$, where T_i is the number of fresh carcasses observed and tagged in tagging week i. $\hat{N}_j$ was calculated as

$$\hat{N}_J = \sum_i \left(R_{i,j} \times \frac{T_i}{R_i} \times \frac{C_j}{R_j} \right).$$

Table 5.9-8. The 2003 spawning escapement estimates in the LFC of the lower Feather River calculated by the Schaefer (1951) mark-recovery method.

$R_{i,j} \times \frac{T_i}{R_i} \times \frac{C_j}{R_j}$															
Week $j \setminus i$	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	$\hat{N}_j$
2	739															739
3	295	1,465														1,760
4	27	293	2,640													2,960
5	30	127	593	5,333												6,082
6	0	39	225	1,185	8,090											9,539
7	0	29	71	106	1,077	8,288										9,572
8	0	0	79	0	312	1,997	7,402									9,790
9	0	0	0	0	18	218	1,202	5,480								6,919
10	0	0	0	0	0	38	180	1,174	4,309							5,702
11	0	0	0	0	0	39	25	194	829	2,717						3,803
12	0	0	0	0	0	15	14	14	170	689	2,136					3,037
13	0	0	0	0	0	0	0	0	23	175	604	1,528				2,330
14	0	0	0	0	0	0	0	0	9	27	62	281	753			1,133
15	0	0	0	0	0	0	0	0	22		21	84	343	385		854
16	0	0	0	0	0	0	0	0	0	0	0	62	78	117	339	597
$\hat{N}_I$	1,090	1,953	3,607	6,624	9,498	10,595	8,822	6,862	5,361	3,608	2,823	1,956	1,174	502	339	64,816
T_i	127	-152	-273	-458	-580	-870	-864	-832	-808	-530	-404	-355	-234	-83	-32	-6,348
Estimated total spawning escapement $\hat{N}$ in the LFC																**58,468**

$\hat{N}_I$ is the estimated portion of the spawning escapement that is available for tagging in tagging week i, and $\hat{N}_j$ is the estimated portion of the spawning escapement that is available for recovery in recovery week j. The estimated total spawning escapement $\hat{N}$ is calculated as $\hat{N} = N_j - \sum_i T_i$, where T_i is the number of fresh carcasses observed and tagged in tagging week i. $\hat{N}_j$ was calculated as $\hat{N}_J = \sum_i \left(R_{i,j} \times \frac{T_i}{R_i} \times \frac{C_j}{R_j} \right)$.

In the HFC, the 2000, 2001, 2002, and 2003 Schaefer variables, calculated using the carcass survey data, used to estimate spawning escapement totals for Chinook salmon in the lower Feather River are shown in Table 5.9-9, Table 5.9-10, Table 5.9-11, and Table 5.9-12, respectively. In the HFC, the yearly ($\hat{N}$) and weekly ($\hat{N}_j$) Schaefer spawning escapement estimates for the 2000, 2001, 2002, and 2003 carcass survey are shown in Table 5.9-13, Table 5.9-14, Table 5.9-15, and Table 5.9-16, respectively. Although both $\hat{N}_j$ and $\hat{N}_i$ represent weekly estimates, $\hat{N}_j$ was used to describe weekly spawning escapement estimates because estimates from this variable are statistically stronger.

In 2000, weekly spawning escapement estimates ranged from 156 (week 3) to 7,152 (week 12), estimates were highest between week 11 and week 13, and the highest estimate occurred during week 12. The greatest positive difference in estimates between adjacent survey weeks occurred between week 4 and week 5 when estimates increased by 3,822. The greatest negative difference in estimates between adjacent survey weeks occurred between week 5 and week 6 when estimates decreased by

2,988. Weekly spawning escapement estimates in the HFC in 2000 showed subtle patterns, with small variation between most weekly estimates. The yearly spawning escapement estimate in the HFC during 2000 was 43,508.

In 2001, weekly spawning escapement estimates ranged from 355 (week 2) to 13,902 (week 10), estimates were highest between week 8 and week 12, and the highest estimate occurred during week 10. The greatest positive difference in estimates between adjacent survey weeks occurred between week 7 and week 8 when estimates increased by 4,637. The greatest negative difference in estimates between adjacent survey weeks occurred between week 12 and week 13 when estimates decreased by 4,378. In general, weekly spawning escapement estimates steadily increased through week 10, then steadily decreased through week 14. The yearly spawning escapement estimate in the HFC during 2001 was 78,049.

In 2002, weekly spawning escapement estimates ranged from 153 (week 16) to 5,330 (week 12), estimates were highest between week 10 and week 12, and the highest estimate occurred during week 12. The greatest positive difference in estimates between adjacent survey weeks occurred between week 9 and week 10 when estimates increased by 2,323. The greatest negative difference in estimates between adjacent survey weeks occurred between week 12 and week 13 when estimates decreased by 2,176. Weekly spawning escapement estimates in the HFC showed subtle patterns, with small variation between most weekly estimates The yearly spawning escapement estimate in the HFC during 2002 was 34,115.

In 2003, weekly spawning escapement estimates ranged from 256 (week 2) to 5,795 (week 13), estimates were highest between week 10 and week 15, and the highest estimate occurred during week 13. The greatest positive difference in estimates between adjacent survey weeks occurred between week 11 and week 12 when estimates increased by 2,331. The greatest negative difference in estimates between adjacent survey weeks occurred between week 14 and week 15 when estimates decreased by 2,044. In general, weekly spawning escapement estimates increased steadily through week 13, then decreased steadily through week 16. The yearly spawning escapement estimate in the HFC during 2003 was 39,600.

Table 5.9-9. Summary of the Schaefer variables used to estimate the 2000 spawning escapement in the HFC of the lower Feather River.

Week	Recovery by Week of Tagging *i* ($R_{i,j}$)																	
j \ *i*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	R_j	C_j	C_j/R_j
2	1 [1]															1	23	23
3		1														1	39	39
4			1 [2]													1	78	78
5				1												1	234	234
6					6											6	219	36.5
7						9										9	455	50.6
8						1	17									18	705	39.2
9							2	19								21	664	31.6
10								8	21							29	1,062	36.6
11								3	5	3						11	1,049	95.4
12								1	2	9	15					27	1,913	70.9
13											4	23				27	985	36.5
14											1	11	6			18	723	40.2
15												3	2	3		8	233	29.1
16																		
R_i	1	1	1	1	6	10	19	31	28	12	20	37	8	3		178	8,382	
T_i	7	4	23	24	72	76	96	131	94	62	58	169	46	9		871		
T_i/R_i	7	4	23	24	12	8	5.1	4.2	3.4	5.2	3	4.6	5.8	3				

[1] One individual marked in week 1 was assumed to have been recovered in week 2 to allow for abundance estimates in weeks 1 and 2.
[2] One individual marked in week 3 was assumed to have been recovered in week 4 to allow for abundance estimates in weeks 3 and 4.
Each cell contains the number of fresh carcasses tagged in tagging week i, and recovered in recovery week j (Ri,,j). Ti is the number of fresh carcasses observed and tagged in tagging week i. Ri is the total number of tags released in tagging week i that were recovered at the end of the carcass survey, and Rj is the number tags recovered in recovery week j. Cj is the total number of carcasses counted in recovery week j. Cj includes the number of decayed carcasses observed and clipped, the number of fresh carcasses observed and tagged, the number of fresh carcasses observed and chopped, and the number of tagged carcasses recovered in week j.

Table 5.9-10. Summary of the Schaefer variables used to estimate the 2001 spawning escapement in the HFC of the lower Feather River.

Week	**Recovery by week of tagging *i* ($R_{i,j}$)**																	
j* \ *i	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**R_j**	**C_j**	**C_j/R_j**
2	3															3	56	18.67
3		1														1	111	111
4			1 [1]													1	198	198
5				2												2	200	100
6				2	2											4	342	85.5
7					1	4										5	392	78.4
8						1	6									7	979	139.86
9							2	17								19	1,911	100.58
10							1	3	16							20	2,221	111.05
11									1	30						31	2,481	80.03
12									1	12	23					36	2,543	70.64
13										2	8	7				17	938	55.18
14										1	4	4	2			11	324	29.45
15																		
16																		
R_i	3	1	1	4	3	5	9	20	18	45	35	11	2			157	12,696	
T_i	19	18	19	36	41	45	78	119	111	197	125	100	26			934		
T_i/R_i	6.33	18	19	9	13.67	9	8.67	5.95	6.17	4.38	3.57	9.09	13					

[1] One individual marked in week 3 was assumed to have been recovered in week 4 to allow for abundance estimates in weeks 3 and 4.
Each cell contains the number of fresh carcasses tagged in tagging week i, and recovered in recovery week j (Ri,,j). Ti is the number of fresh carcasses observed and tagged in tagging week i. Ri is the total number of tags released in tagging week i that were recovered at the end of the carcass survey, and Rj is the number tags recovered in recovery week j. Cj is the total number of carcasses counted in recovery week j. Cj includes the number of decayed carcasses observed and clipped, the number of fresh carcasses observed and tagged, the number of fresh carcasses observed and chopped, and the number of tagged carcasses recovered in week j.

Table 5.9-11. Summary of the Schaefer variables used to estimate the 2002 spawning escapement in the HFC of the lower Feather River.

Week	**Recovery by week of tagging *i* ($R_{i,j}$)**																	
j* \ *i	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	R_j	C_j	C_j/R_j
2	2															2	54	27
3		1 [1]														1	53	53
4			3													3	123	41
5				1												1	107	107
6				1	7											8	220	27.5
7					1	6										7	416	59.4
8						2	29									31	792	25.6
9							3	27								30	647	21.6
10							1	11	27							39	1,205	30.9
11								3	10	70						83	1,574	19
12								1	3	22	84					110	2,041	18.6
13										1	22	49				72	937	13
14											6	11	19			36	499	13.9
15								1				2	4	7		14	190	13.6
16															1 [2]	2	26	13
R_i	2	1	3	2	8	8	33	43	40	93	112	63	23	7	1	439	8,884	
T_i	14	27	26	33	35	53	125	183	167	281	272	239	85	29	8	1,577		
T_i/R_i	7	27	8.7	17	4.4	6.6	3.8	4.3	4.2	3	2.4	3.8	4	4.1	8			

[1] One individual marked in week 2 was assumed to have been recovered in week 3 to allow for abundance estimates in weeks 2 and 3.

[2] One individual marked in week 15 was assumed to have been recovered in week 16 to allow for abundance estimates in week 15.

Each cell contains the number of fresh carcasses tagged in tagging week i, and recovered in recovery week j (Ri,,j). Ti is the number of fresh carcasses observed and tagged in tagging week i. Ri is the total number of tags released in tagging week i that were recovered at the end of the carcass survey, and Rj is the number tags recovered in recovery week j. Cj is the total number of carcasses counted in recovery week j. Cj includes the number of decayed carcasses observed and clipped, the number of fresh carcasses observed and tagged, the number of fresh carcasses observed and chopped, and the number of tagged carcasses recovered in week j.

Table 5.9-12. Summary of the Schaefer variables used to estimate the 2003 spawning escapement in the HFC of the lower Feather River.

Week	**Recovery by Week of Tagging *i* ($R_{i,j}$)**																	
j* \ *i	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	R_j	C_j	C_j/R_j
2	1 [1]															1	32	32.00
3		1 [2]														1	80	80.00
4			3													3	129	43.00
5				6												6	231	38.50
6				1	6											7	255	36.43
7					1	9										10	288	28.80
8						5	11									16	310	19.38
9							2	9								11	364	33.09
10								1	10							11	626	56.91
11									4	36						40	940	23.50
12									1	13	45					59	1,948	33.02
13										3	26	113				142	2,158	15.20
14											13	49	67			129	1,842	14.28
15									1			6	11	21		39	699	17.92
16												6	3	5	2	16	492	30.75
R_i	1	1	3	7	7	14	13	10	16	52	84	174	81	26	2	491	10,394	
T_i	8	15	23	35	54	64	71	87	97	175	232	461	253	159	20	1,754		
T_i/R_i	8.00	15.00	7.67	5.00	7.71	4.57	5.46	8.70	6.06	3.37	2.76	2.65	3.12	6.12	10.00			

[1] One individual marked in week 1 was assumed to have been recovered in week 2 to allow for abundance estimates in weeks 1 and 2.

[2] One individual marked in week 2 was assumed to have been recovered in week 3 to allow for abundance estimates in weeks 2 and 3.

Each cell contains the number of fresh carcasses tagged in tagging week i, and recovered in recovery week j (Ri,,j). Ti is the number of fresh carcasses observed and tagged in tagging week i. Ri is the total number of tags released in tagging week i that were recovered at the end of the carcass survey, and Rj is the number tags recovered in recovery week j. Cj is the total number of carcasses counted in recovery week j. Cj includes the number of decayed carcasses observed and clipped, the number of fresh carcasses observed and tagged, the number of fresh carcasses observed and chopped, and the number of tagged carcasses recovered in week j.

Table 5.9-13. The 2000 spawning escapement estimates in the HFC of the lower Feather River calculated by the Schaefer (1951) mark-recovery method.

$$R_{i,j} \times \frac{T_i}{R_i} \times \frac{C_j}{R_j}$$

Week $j \setminus i$	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	$\hat{N}_j$
2	161															161
3	0	156														156
4	0	0	1,794													1,794
5	0	0	0	5,616												5,616
6	0	0	0	0	2,628											2,628
7	0	0	0	0	0	3,458										3,458
8	0	0	0	0	0	298	3,364									3,662
9	0	0	0	0	0	0	320	2,539								2,858
10	0	0	0	0	0	0	0	1,238	2,582							3,820
11	0	0	0	0	0	0	0	1,209	1,601	1,478						4,288
12	0	0	0	0	0	0	0	299	476	3,295	3,082					7,152
13	0	0	0	0	0	0	0	0	0	0	423	3,833				4,256
14	0	0	0	0	0	0	0	0	0	0	116	2,018	1,386			3,520
15	0	0	0	0	0	0	0	0	0	0	0	399	335	262		996
16																
$\hat{N}_I$	161	156	1,794	5,616	2,628	3,756	3,684	5,285	4,658	4,773	3,622	6,250	1,721	262		44,365
T_i	7	-4	-23	-24	-72	-76	-96	-131	-94	-62	-58	-169	-46	-9		-857
Estimated total spawning escapement $\hat{N}$ in the HFC																**43,508**

$\hat{N}_I$ is the estimated portion of the spawning escapement available for tagging in tagging week I, and $\hat{N}_j$ is the estimated portion of the spawning escapement available for recovery in recovery week j. The estimated total spawning escapement $\hat{N}$ is calculated as $\hat{N} = N_j - \sum_i T_i$, where T_i is the number of fresh carcasses observed and tagged in tagging week i and $\hat{N}_j$ was calculated as $\hat{N}_j = \sum_i \left(R_{i,j} \times \frac{T_i}{R_i} \times \frac{C_j}{R_j} \right)$.

Table 5.9-14. The 2001 spawning escapement estimates in the HFC of the lower Feather River calculated by the Schaefer (1951) mark-recovery method.

$$R_{i,j} \times \frac{T_i}{R_i} \times \frac{C_j}{R_j}$$

Week $j \setminus i$	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	$\hat{N}_j$
2	355															355
3	0	1,998														1,998
4	0	0	3,762													3,762
5	0	0	0	1,800												1,800
6	0	0	0	1,539	2,337											3,876
7	0	0	0	0	1,071	2,822										3,894
8	0	0	0	0	0	1,259	7,273									8,531
9	0	0	0	0	0	0	1,743	10,174								11,917
10	0	0	0	0	0	0	962	1,982	10,957							13,902
11	0	0	0	0	0	0	0	0	494	10,511						11,004
12	0	0	0	0	0	0	0	0	436	3,711	5,802					9,949
13	0	0	0	0	0	0	0	0	0	483	1,576	3,511				5,571
14	0	0	0	0	0	0	0	0	0	129	421	1,071	766			2,387
15																
16																
$\hat{N}_I$	355	1,998	3,762	3,339	3,408	4,081	9,978	12,156	11,886	14,834	7,800	4,582	766			78,945
T_i	19	-18	-19	-36	-41	-45	-78	-119	-111	-197	-125	-100	-26			-896
Estimated total spawning escapement $\hat{N}$ in the HFC																**78,049**

$\hat{N}_I$ is the estimated portion of the spawning escapement available for tagging in tagging week i, and $\hat{N}_j$ is the estimated portion of the spawning escapement available for recovery in recovery week j. The estimated total spawning escapement $\hat{N}$ is calculated as $\hat{N} = N_j - \sum_i T_i$, where T_i is the number of fresh carcasses observed and tagged in tagging week i and $\hat{N}_j$ was calculated as $\hat{N}_j = \sum_i \left(R_{i,j} \times \frac{T_i}{R_i} \times \frac{C_j}{R_j} \right)$.

Table 5.9-15. The 2002 spawning escapement estimates in the HFC of the lower Feather River calculated by the Schaefer (1951) mark-recovery method.

$$R_{i,j} \times \frac{T_i}{R_i} \times \frac{C_j}{R_j}$$

Week J \ i	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	$\hat{N}_j$
2	378															378
3	0	1,431														1,431
4	0	0	1,066													1,066
5	0	0	0	1,766												1,766
6	0	0	0	454	842											1,296
7	0	0	0	0	260	2,362										2,622
8	0	0	0	0	0	339	2,806									3,145
9	0	0	0	0	0	0	245	2,478								2,723
10	0	0	0	0	0	0	117	1,446	3,483							5,046
11	0	0	0	0	0	0	0	242	792	4,011						5,045
12	0	0	0	0	0	0	0	79	232	1,233	3,785					5,330
13	0	0	0	0	0	0	0	0	0	39	695	2,419				3,154
14	0	0	0	0	0	0	0	0	0	0	202	578	973			1,754
15	0	0	0	0	0	0	0	58	0	0	0	103	201	394		755
16	0	0	0	0	0	0	0	0	0	0	0	49	0	0	104	153
$\hat{N}_I$	378	1,431	1,066	2,219	1,102	2,701	3,169	4,303	4,507	5,284	4,682	3,150	1,174	394	104	35,664
T_i	14	-27	-26	-33	-35	-53	-125	-183	-167	-281	-272	-239	-85	-29	-8	-1,549
Estimated total spawning escapement $\hat{N}$ in the HFC																**34,115**

$\hat{N}_I$ is the estimated portion of the spawning escapement available for tagging in tagging week i, and $\hat{N}_j$ is the estimated portion of the spawning escapement available for recovery in recovery week j. The estimated total spawning escapement $\hat{N}$ is calculated as $\hat{N} = N_j - \sum_i T_i$, where T_i is the number of fresh carcasses observed and tagged in tagging week i and $\hat{N}_j$ was calculated as $\hat{N}_j = \sum_i \left(R_{i,j} \times \frac{T_i}{R_i} \times \frac{C_j}{R_j} \right)$.

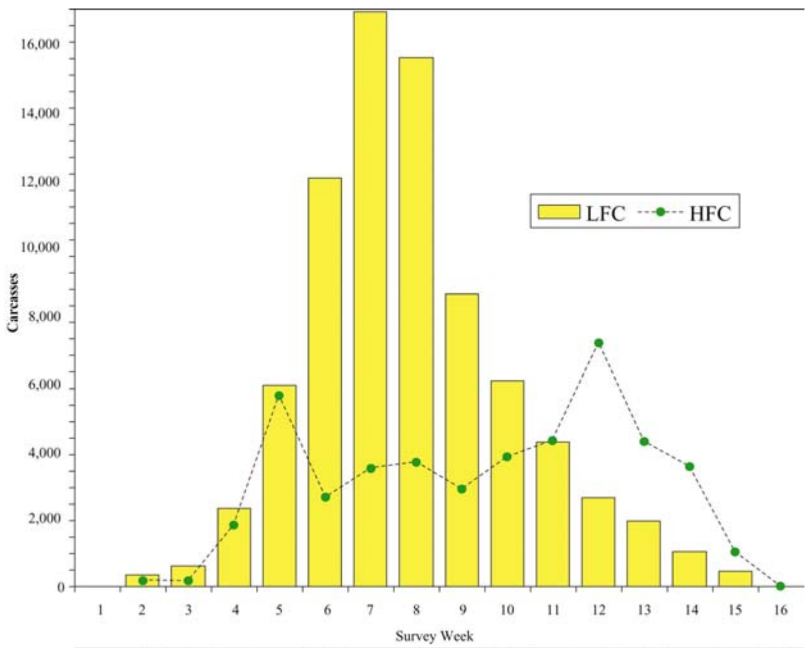
Table 5.9-16. The 2003 spawning escapement estimates in the HFC of the lower Feather River calculated by the Schaefer (1951) mark-recovery method.

$$R_{i,j} \times \frac{T_i}{R_i} \times \frac{C_j}{R_j}$$

Week $j \setminus i$	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	$\hat{N}_j$
2	256															256
3	0	1,200														1,200
4	0		989													989
5	0	0	0	1,155												1,155
6	0	0	0	182	1,686											1,868
7	0	0	0		222	1,185										1,407
8	0	0	0	0	0	443	1,164									1,607
9	0	0	0	0	0		361	2,591								2,952
10	0	0	0	0	0	0	0	495	3,450							3,945
11	0	0	0	0	0	0	0	0	570	2,847						3,417
12	0	0	0	0	0	0	0	0	200	1,444	4,104					5,748
13	0	0	0	0	0	0	0	0	0	153	1,091	4,550				5,795
14	0	0	0	0	0	0	0	0	0	0	513	1,854	2,988			5,355
15	0	0	0	0	0	0	0	0	109	0	0	285	616	2,302		3,311
16	0	0	0	0	0	0	0	0	0	0	0	489	288	940	615	2,332
$\hat{N}_I$	256	1,200	989	1,337	1,908	1,628	1,525	3,086	4,329	4,445	5,708	7,177	3,892	3,242	615	41,338
T_i	8	-15	-23	-35	-54	-64	-71	-87	-97	-175	-232	-461	-253	-159	-20	-1,738
Estimated total spawning escapement $\hat{N}$ in the HFC																**39,600**

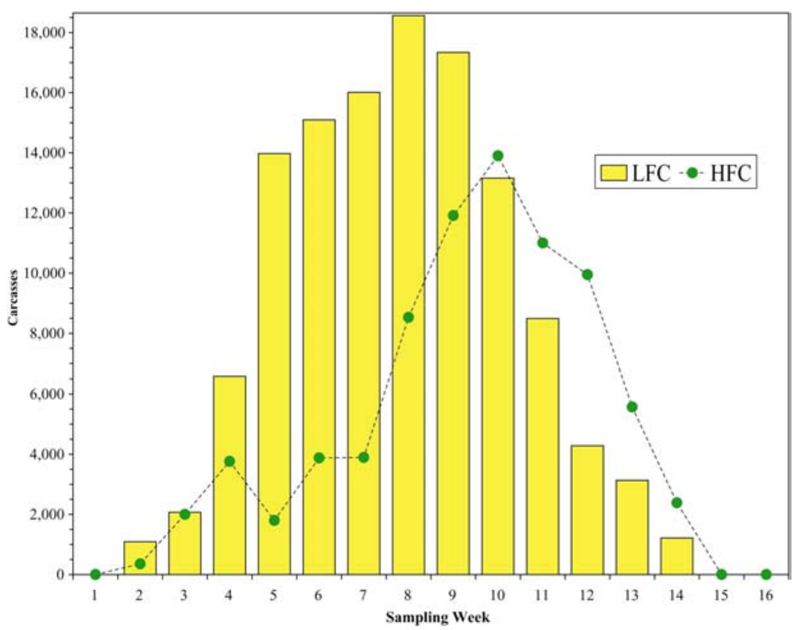
$\hat{N}_I$ is the estimated portion of the spawning escapement available for tagging in tagging week i, and $\hat{N}_j$ is the estimated portion of the spawning escapement available for recovery in recovery week j. The estimated total spawning escapement $\hat{N}$ is calculated as $\hat{N} = N_j - \sum_i T_i$, where T_i is the number of fresh carcasses observed and tagged in tagging week i and $\hat{N}_j$ was calculated as $\hat{N}_j = \sum_i \left(R_{i,j} \times \frac{T_i}{R_i} \times \frac{C_j}{R_j} \right)$.

The spatial and temporal distribution of spawning escapement estimates for 2000, 2001, 2002, and 2003 are shown in Figure 5.9-1, Figure 5.9-2, Figure 5.9-3 and Figure 5.9-4, respectively. In 2000, escapement estimates between reaches generally were similar through the first 5 survey weeks. During week 6 through week 10, estimates generally were much higher in the LFC. During week 11 through 16, estimates generally were higher in the HFC. In 2001, escapement estimates generally were much higher in the LFC from week 4 through week 9, and higher in the HFC from week 10 through week 14. In 2002, the temporal trend in estimate densities was similar to that of the 2001 survey season, except that estimates in the HFC exceeded those in the LFC during week 11. In 2003, escapement estimates in the LFC significantly exceeded escapement estimates in the HFC from week 4 through week 9. Escapement estimates in the HFC began increasing steadily in week 9, and exceeded escapement estimates in the LFC from week 12 through week 16. In general, for all survey years, there was greater variation between weekly estimates in the LFC, and no clear temporal trend between weekly estimates in the HFC. For all survey years, the highest spawning escapement estimates occurred earlier during the survey period in the LFC, and later in the survey period in the HFC.



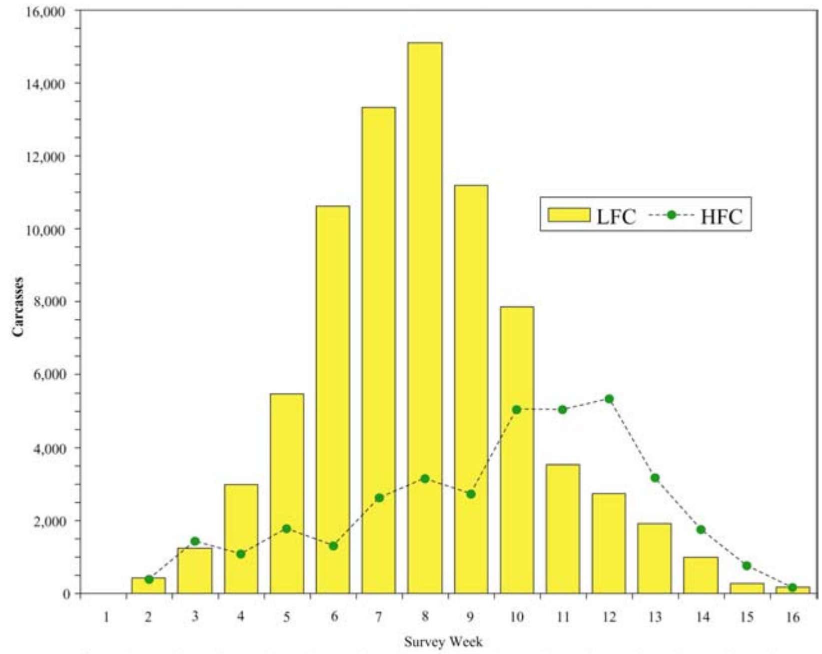
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
From	9/5	9/12	9/18	9/25	10/2	10/10	10/16	10/23	10/30	11/6	11/13	11/20	11/27	12/4	12/11	
To	9/6	9/15	9/21	9/28	10/6	10/13	10/20	10/27	11/2	11/9	11/16	11/22	11/30	12/7	12/14	

Figure 5.9-1. The 2000 Schaefer spawning escapement estimates, by survey week and reach, for Chinook salmon in the lower Feather River.



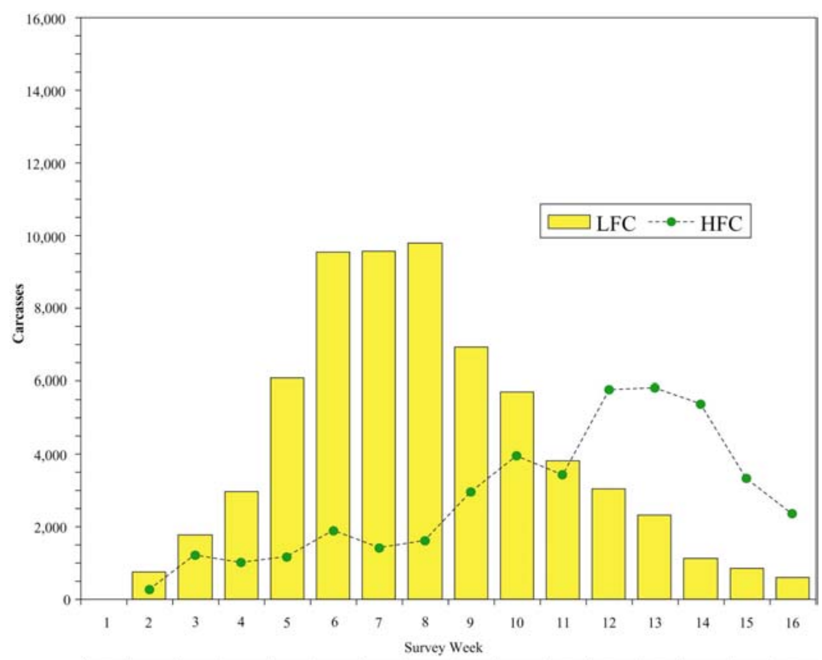
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
From	9/10	9/17	9/24	10/1	10/8	10/15	10/22	10/29	11/5	11/13	11/19	11/25	12/3	12/10		
To	9/14	9/21	9/28	10/4	10/11	10/18	10/25	11/1	11/8	11/15	11/21	11/29	12/6	12/13		

Figure 5.9-2. The 2001 Schaefer spawning escapement estimates, by survey week and reach, for Chinook salmon in the lower Feather River.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
From	9/3	9/9	9/16	9/23	9/30	10/7	10/14	10/21	10/28	11/4	11/11	11/18	11/25	12/2	12/9	12/16
To	9/5	9/12	9/19	9/26	10/4	10/10	10/17	10/25	10/31	11/8	11/14	11/21	11/27	12/5	12/11	12/19

Figure 5.9-3. The 2002 Schaefer spawning escapement estimates, by survey week and reach, for Chinook salmon in the lower Feather River.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
From	9/2	9/8	9/15	9/22	9/29	10/4	10/11	10/18	10/25	11/3	11/10	11/15	11/24	12/1	12/8	12/15
To	9/4	9/10	9/17	9/24	10/2	10/9	10/16	10/23	10/30	11/6	11/13	11/20	11/28	12/4	12/11	12/17

Figure 5.9-4. The 2003 Schaefer spawning escapement estimates, by survey week and reach, for Chinook salmon in the lower Feather River.

5.10 INSTREAM FLOW AND SPAWNING HABITAT AVAILABILITY

The habitat availability-flow curve, generated using PHABSIM methodology, depicting instream flow and the corresponding WUA index for Chinook salmon spawning habitat in the LFC is shown in Figure 5.10-1. From a low value at 150 cfs, the lowest flow modeled, the habitat index rises sharply to a peak near 700 cfs. Beyond the peak, the index falls sharply again out to about 1800 cfs, where the rate of fall begins to become asymptotic with the x-axis. At a flow of 700 to 725 cfs the maximum physical habitat for Chinook salmon spawning at a fixed (rather than variable) flow is provided. The habitat availability-flow curve, generated using PHABSIM methodology, depicting instream flow and the corresponding WUA index for Chinook salmon spawning habitat in the HFC is shown in Figure 5.10-2. The WUA index in the HFC is similar to the LFC in relation to discharge, rising from a low level at the lowest modeled flow of 500 cfs to peak near 1,500 cfs, above which it declines out to 7000 cfs. Maximum physical habitat for Chinook salmon spawning in the broader, lower gradient HFC occurs at a flow of about 1,500 cfs, slightly more than twice the flow of the maximum index in the LFC.

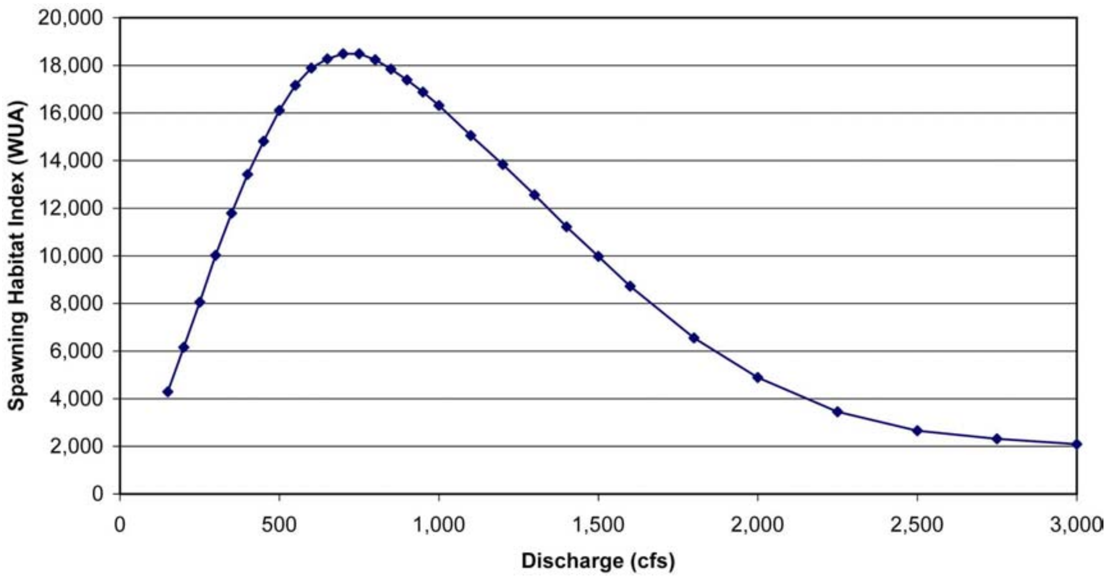


Figure 5.10-1. Instream flow and corresponding spawning habitat index (WUA) values in the LFC of the lower Feather River.

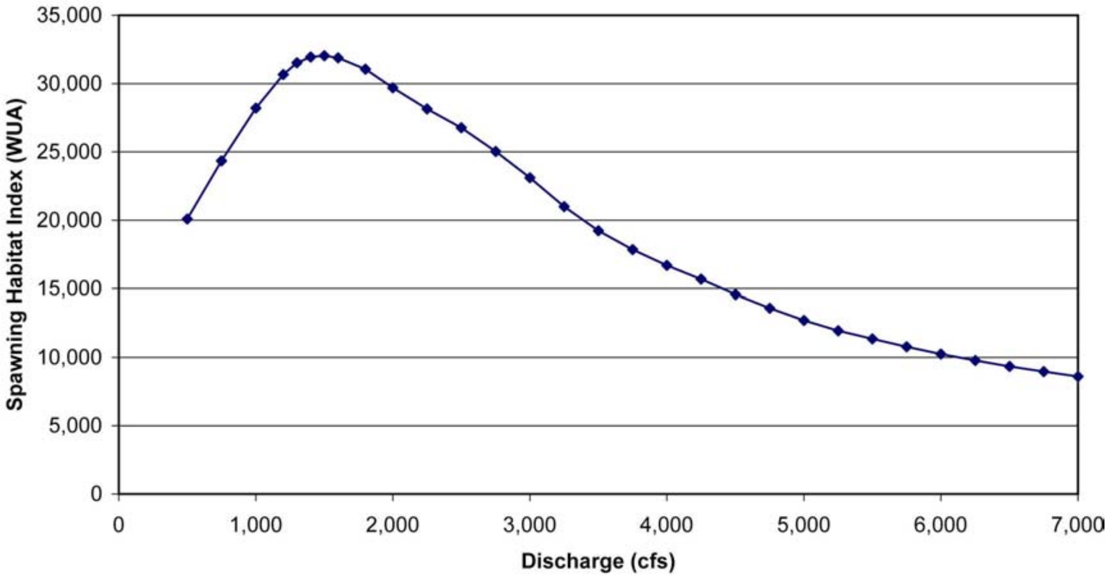


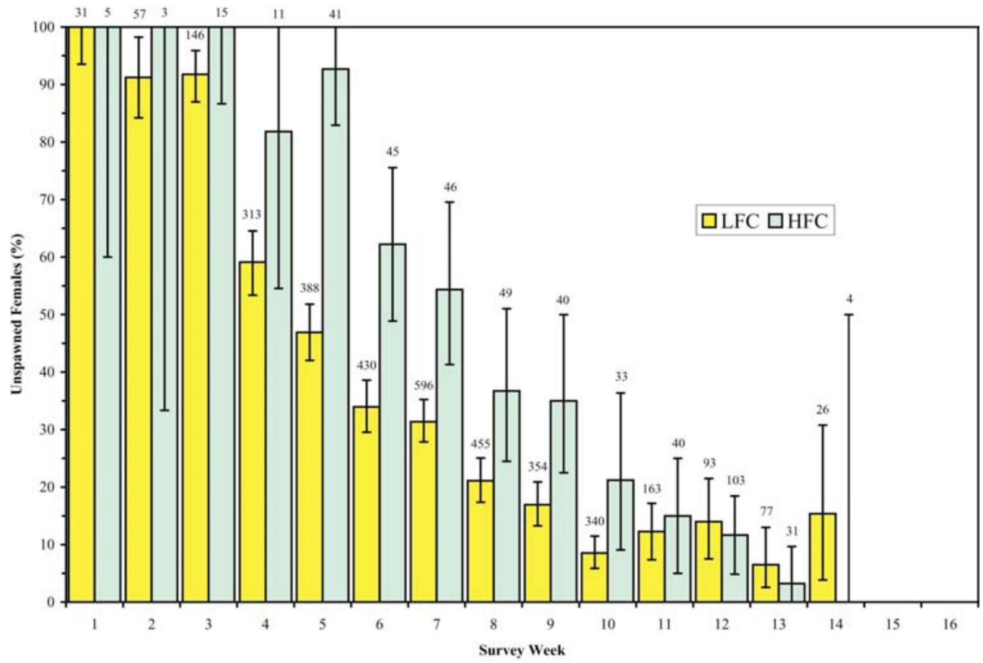
Figure 5.10-2. Instream flow and corresponding spawning habitat index (WUA) values in the HFC of the lower Feather River.

5.11 PRE-SPAWN MORTALITY

Pre-spawn mortality estimates and regression analyses for 2000, 2001, 2002, and 2003 are summarized below. In general, annual patterns of pre-spawn mortality were similar among sample years. To prevent repetitive analyses, the 2002 data was chosen as representative of pre-spawn mortality characteristics, and a more detailed analysis was conducted with these data.

5.11.1 Pre-Spawn Mortality Estimates

During the 2000 mark-recapture and CWT carcass surveys, 3,935 female carcasses were sampled for egg retention. The pre-spawn mortality estimates by survey week and reach, expressed as a percentage, are shown in Figure 5.11-1. Pre-spawn mortality estimates were generally negatively correlated with time, showing decreases in both reaches as the surveys progressed. The weekly pre-spawn mortality estimates showed similar temporal trends in both reaches, with estimates ranging from approximately 80 to 100 percent during the first three to four weeks of the survey period, and decreasing to approximately 15 percent during the last four weeks. Estimates for both reaches were highest during weeks 1 through 5 (September 5 through October 6). In general, weekly pre-spawn mortality estimates were higher in the HFC than in the LFC. Table 5.11-1 summarizes the pre-spawn mortalities (expressed as a percentage), standard errors, and 95 percent confidence intervals by reach and survey period. Pre-spawn mortality estimates were similar for both reaches, with slightly higher estimates in the HFC, although the standard error for the HFC was more than twice that for the LFC. The corresponding confidence intervals also were wider for the HFC.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
From	9/5	9/12	9/18	9/25	10/2	10/10	10/16	10/23	10/30	11/6	11/13	11/20	11/27	12/4	12/11	
To	9/6	9/15	9/21	9/28	10/6	10/13	10/20	10/27	11/2	11/9	11/16	11/22	11/30	12/7	12/14	

Figure 5.11-1. The 2000 pre-spawn mortality estimates (expressed as a percentage), by survey week and reach, for Chinook salmon in the lower Feather River. Error bars indicate the 95% confidence intervals, and the numbers represent sample sizes.

Table 5.11-1. Pre-spawn mortality variables, calculated by reach and survey period, for the 2000 carcass survey data.

	LFC	HFC
Mortality Estimate (%)	33.0	38.8
Standard Error	0.7	1.7
95% Confidence Interval	(31.7 - 34.3)	(35.2 - 41.9)

During the 2001 mark-recapture and CWT carcass surveys, 3,622 female carcasses were sampled for egg retention. The pre-spawn mortality estimates by survey week and reach, expressed as a percentage, are shown in Figure 5.11-2. Pre-spawn mortality estimates were generally negatively correlated with time, showing decreases in both reaches as the surveys progressed. The weekly pre-spawn mortality estimates showed similar temporal trends in both reaches with estimates ranging from approximately 60 to 100 percent during the first six weeks of the survey period, and decreasing to below 30 percent during the last three weeks. Estimates for both reaches were highest during weeks 1 through 6 (September 10 through October 18), and did not decrease below 50 percent until week 8 (October 29 through November 1). In general, weekly pre-spawn mortality estimates were higher in the HFC than in the LFC. Table 5.11-2 summarizes the pre-spawn mortalities (expressed as a percentage), standard errors, and 95 percent confidence intervals by reach and survey period. Pre-spawn mortality estimates were slightly higher in the LFC than in the HFC. The standard error for the HFC was approximately twice that for the LFC. The corresponding confidence intervals also were wider for the HFC.

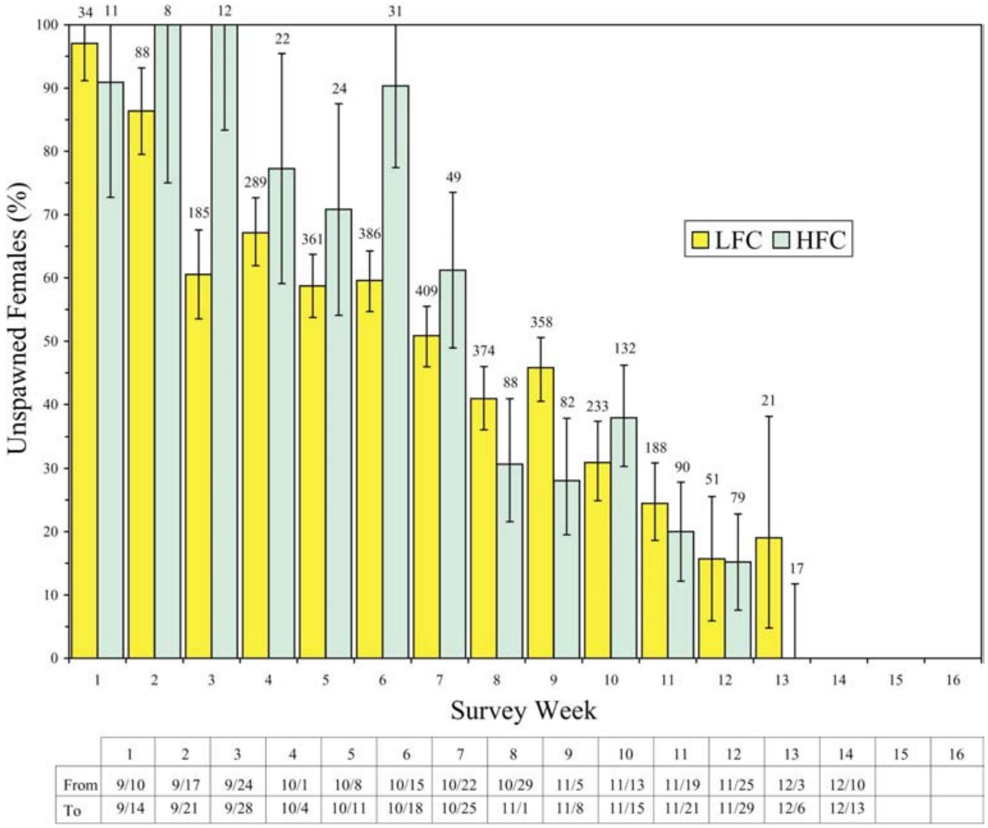
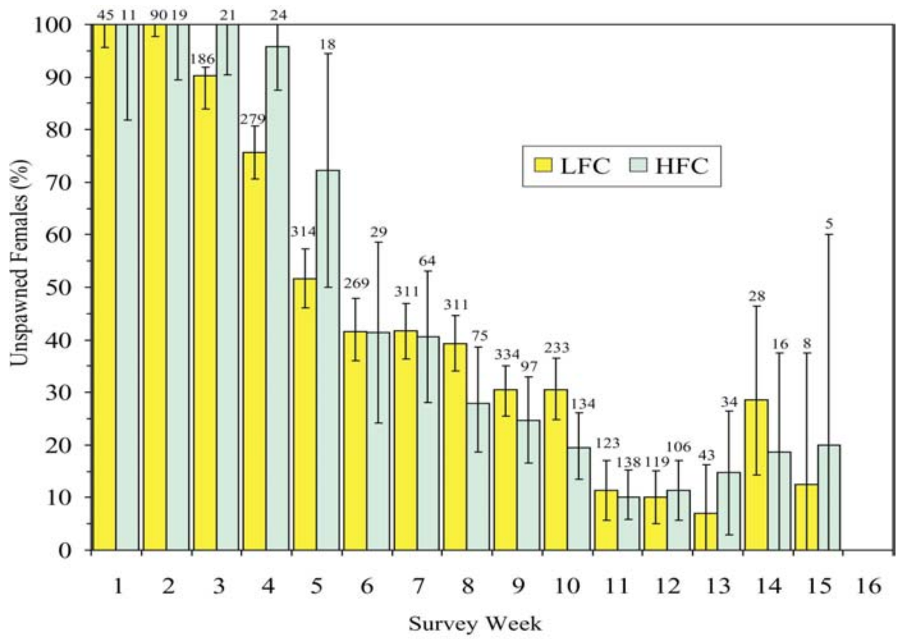


Figure 5.11-2. The 2001 pre-spawn mortality estimates (expressed as a percentage) by survey week and reach, for Chinook salmon in the lower Feather River. Error bars indicate the 95% confidence intervals and the numbers represent sample sizes.

Table 5.11-2. Pre-spawn mortality variables, calculated by reach and survey period, for the 2001 carcass survey data.

	LFC	HFC
Mortality Estimate (%)	50.8	39.1
Standard Error	0.9	1.7
95% Confidence Interval	(49.2 - 52.4)	(35.7 - 42.5)

During the 2002 mark-recapture and CWT carcass surveys, 3,484 female carcasses were sampled for egg retention. The pre-spawn mortality estimates by survey week and reach, expressed as a percentage, are shown in Figure 5.11-3. Pre-spawn mortality estimates were generally negatively correlated with time, showing decreases in both reaches as the surveys progressed. Temporal trends were similar in both reaches with pre-spawn mortality estimates ranging from approximately 75 to 100 percent during the first four weeks of the survey period, and decreasing to approximately 15 percent during the last four weeks. Estimates for both reaches were highest during weeks 1 through 5 (September 5 through October 6). In general, weekly pre-spawn mortality estimates were higher in the HFC in the first several survey weeks, and higher in the LFC during the middle of the survey period (weeks 6-11; October 7 through November 14).



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
From	9/3	9/9	9/16	9/23	9/30	10/7	10/14	10/21	10/28	11/4	11/11	11/18	11/25	12/2	12/9	12/16
To	9/5	9/12	9/19	9/26	10/4	10/10	10/17	10/25	10/31	11/8	11/14	11/21	11/27	12/5	12/11	12/19

Figure 5.11-3. The 2002 pre-spawn mortality estimates (expressed as a percentage) by survey week and reach, for Chinook salmon in the lower Feather River. Error bars indicate the 95% confidence intervals and the numbers represent sample sizes.

The pre-spawn mortality estimates by survey month, section/unit, and reach are shown in Figures A-12 through A-15. In the LFC, pre-spawn mortality estimates were negatively correlated with survey month. In September, pre-spawn mortality estimates were the highest, when most section/units recorded values greater than 70 percent. Estimates were lowest in the section/units located in the first couple of miles downstream from the fish hatchery (section/unit 1-9). The most downstream section/units in the LFC had the highest pre-spawn mortality estimates (section/unit 13-23), with estimates in many section/units approaching 100 percent. In October, pre-spawn mortality estimates decreased, while sample sizes increased. In the upstream portion of the LFC (section/unit 1-10), estimates generally did not exceed 40 percent, while for the remainder of the LFC, estimates were generally higher. In November, pre-spawn mortality estimates generally were well below 40 percent, with the exception of section/unit 1 (51 to 60 percent) and section/unit 10 (41 to 50 percent). Pre-spawn mortality estimates in December were high in many section/units, however, sample sizes were likely too low for calculating reliable estimates.

In the HFC, pre-spawn mortality estimates were negatively correlated with survey month (Figures A-12 through A-15). However, this may not be a true reflection of temporal trends because monthly sample sizes were highly variable. In September, all sections/units except one (section/unit 28) had estimates of 100 percent, but sample sizes were very low. In October, estimates decreased and sample sizes increased. In general, the highest estimates were found in the downstream section/units. In November, estimates continued to decrease while sample sizes increased, and the spatial trends were similar to preceding months. Estimates for December were not useful due to small sample sizes.

The pre-spawn mortality estimates by survey month and reach are shown in Figure 5.11-4. Estimates decreased in both reaches from September through November. December pre-spawn mortality estimates increased slightly from the preceding month. However, sample sizes were smallest in December, and the corresponding confidence intervals the greatest. In the LFC, estimates in September had a 95 percent confidence interval ranging between 72.4 to 78.5 percent, and estimates in November had a 95 percent confidence interval ranging between 15.8 to 22.8 percent. In the HFC, estimates in September had a 95 percent confidence interval ranging between 97.3 to 100 percent, and estimates in November had a 95 percent confidence interval ranging between 10.4 to 17.2 percent. Pre-spawn mortality estimates were highest in the LFC from October through December, and highest in the HFC in September.

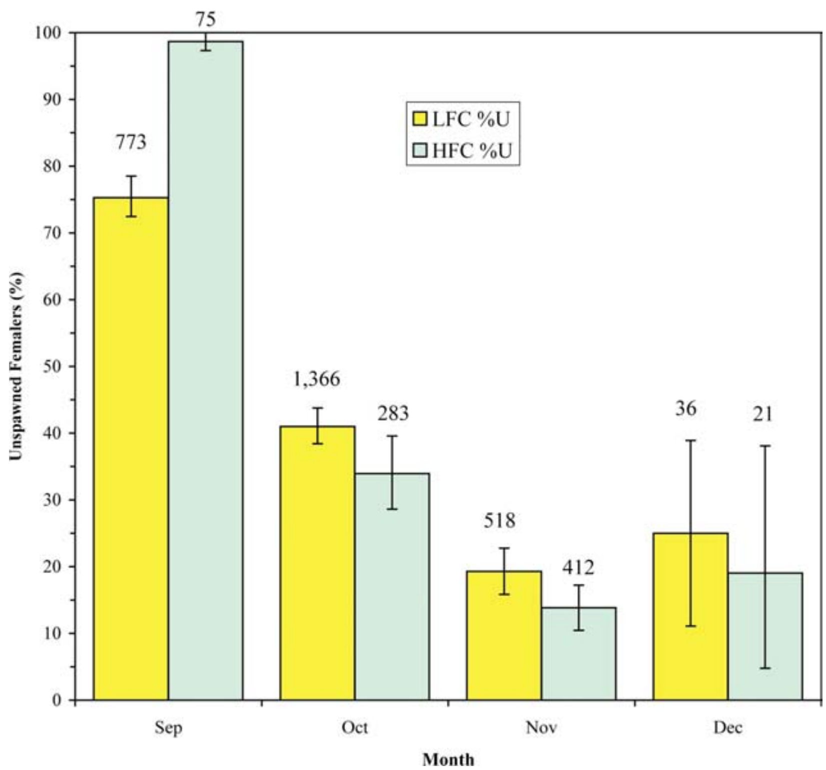
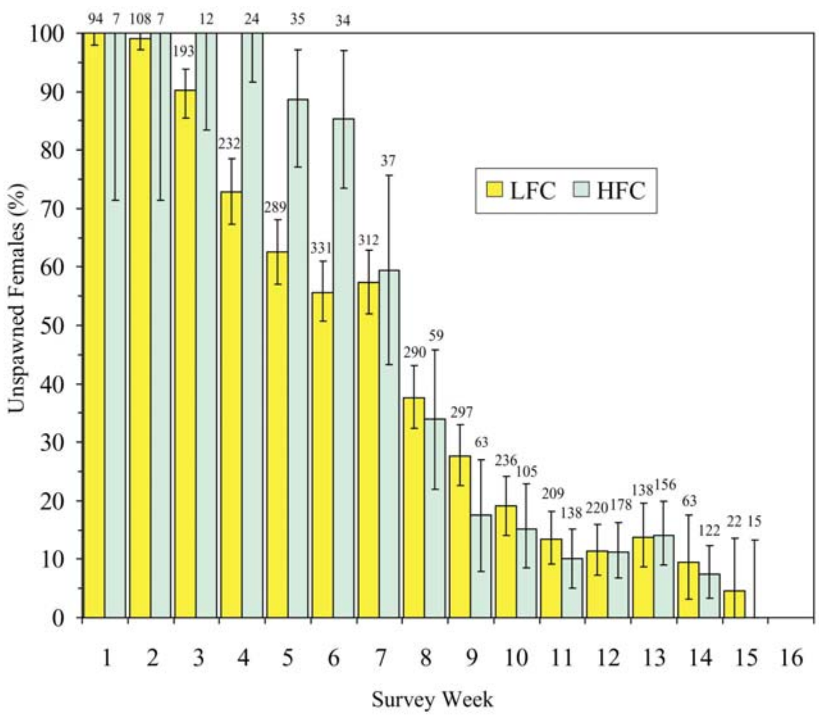


Figure 5.11-4. The 2002 pre-spawn mortality estimates (expressed as a percentage), by survey month and reach, for Chinook salmon in the lower Feather River. Error bars indicate the 95% confidence intervals, and the numbers represent sample sizes.

The pre-spawn mortality estimates by survey period, section/unit, and reach are shown in Figure A-16. In general, pre-spawn mortality estimates and sample sizes were higher in the LFC than in the HFC. In the LFC, there were no clear spatial trends except that estimates were generally lower in the upstream portion of the reach (section/unit 2-9). In the HFC, pre-spawn mortality estimates were generally positively correlated with downstream location, and the most downstream section/units had the highest estimates (section/unit 44-46).

During the 2003 mark-recapture and CWT carcass surveys, 4,026 female carcasses were sampled for egg retention. The pre-spawn mortality estimates by survey week and reach, expressed as a percentage, are shown in Figure 5.11-5. Pre-spawn mortality estimates were generally negatively correlated with time, showing decreases in both reaches as the surveys progressed. The weekly pre-spawn mortality estimates showed similar temporal trends in both reaches with estimates ranging from approximately 60 to 100 percent during the first 7 weeks of the survey period, and decreasing to approximately 15 percent during the last four weeks. Estimates for both reaches were highest during weeks 1 through 5 (September 5 through October 6). Weekly pre-spawn mortality estimates were higher in the HFC than in the LFC through week 7. In general, weekly pre-spawn mortality estimates were higher in the LFC than in the LFC from week 8 through week 15. Table 5.11-3 summarizes the pre-spawn mortalities (expressed as a percentage), standard errors, and 95 percent confidence intervals by reach and survey period. Pre-spawn mortality estimates were slightly higher in the LFC than in the HFC. The standard error for both reaches was small, and the confidence interval for both reaches was narrow.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
From	9/2	9/8	9/15	9/22	9/29	10/4	10/11	10/18	10/25	11/3	11/10	11/15	11/24	12/1	12/8	12/15
To	9/4	9/10	9/17	9/24	10/2	10/9	10/16	10/23	10/30	11/6	11/13	11/20	11/28	12/4	12/11	12/17

Figure 5.11-5. The 2003 pre-spawn mortality estimates (expressed as a percentage) by survey week and reach, for Chinook salmon in the lower Feather River. Error bars indicate the 95% confidence intervals and the numbers represent sample sizes.

Table 5.11-3. Pre-spawn mortality variables, calculated by reach and survey period, for the 2003 carcass survey data.

	LFC	HFC
Mortality Estimate (%)	46.2	38.8
Standard Error	0.8	1.1
95% Confidence Interval	(44.7 - 47.8)	(22.3 - 26.5)

5.11.2 Pre-Spawn Mortality Regression Analyses

Results from the pre-spawn mortality regression analyses for the LFC and the HFC are summarized below for the 2002 carcass survey data.

5.11.2.1 Pre-Spawn Mortality Regression Analyses in the LFC of the Lower Feather River

The variables used in the weighted regression analyses for the 2002 weekly pre-spawn mortality estimates in the LFC are shown in Table 5.11-4. The results from weighted least squares regressions of the logit transformation of the weekly pre-spawn mortality estimates in the LFC are shown in Table 5.11-5.

Table 5.11-4. Variables used in the weighted regression analysis of the 2002 weekly pre-spawn mortality estimates in the LFC (P).

P	*Logit P*	*Var. P*	*Weight*	*Week*	*Escapement*	*AT2*	*AVarT2*	*AT3*	*AVarT3*	*AT4*	*AVarT4*
1	4.4886	0.0003	3,876	1	---	15.07	0.9872	15.02	1.1545	15.89	1.411
1	5.1874	0.0001	14,826	2	427	13.73	1.783	15.07	0.9872	15.02	1.1545
0.9032	2.2336	0.0004	2,270	3	1,255	12.91	1.1156	13.73	1.783	15.07	0.9872
0.7563	1.1324	0.0006	1,567	4	2,995	11.87	1.5812	12.91	1.1156	13.73	1.783
0.5159	0.0637	0.0008	1,264	5	5,485	11.75	1.3876	11.87	1.5812	12.91	1.1156
0.4164	-0.3377	0.0009	1,111	6	10,614	12	0.8277	11.75	1.3876	11.87	1.5812
0.418	-0.331	0.0008	1,331	7	13,321	12.14	0.4899	12	0.8277	11.75	1.3876
0.3923	-0.4377	0.0007	1,372	8	15,111	13.28	0.2692	12.14	0.4899	12	0.8277
0.3054	-0.8218	0.0006	1,616	9	11,182	13.61	0.1296	13.28	0.2692	12.14	0.4899
0.3047	-0.8249	0.0009	1,099	10	7,851	13.4	0.0646	13.61	0.1296	13.28	0.2692
0.1138	-2.0523	0.0009	1,163	11	3,533	13.02	0.0459	13.4	0.0646	13.61	0.1296
0.1008	-2.1879	0.0007	1,501	12	2,745	12.42	0.0322	13.02	0.0459	13.4	0.0646
0.0698	-2.5903	0.0015	677	13	1,929	12.74	0.0191	12.42	0.0322	13.02	0.0459
0.2857	-0.9163	0.0071	140	14	1,000	12.43	0.0224	12.74	0.0191	12.42	0.0322
0.125	-1.9459	0.0137	73	15	279	12.03	0.0688	12.43	0.0224	12.74	0.0191
---	---	---	---	16	179	12.04	0.0626	12.03	0.0688	12.43	0.0224

AT2, AT3, and AT4 represent the weekly averages of the mean daily water temperatures (oC) in the LFC, calculated 2, 3, and 4 weeks before the start of each survey sampling week. AvarT2, AvarT3, and AVarT4 represent the weekly averages of the mean daily water temperature variances (oC) in the LFC, calculated 2, 3, and 4 weeks before the start of each survey sampling week. Week represents the survey sampling week. Escapement represents the spawning escapement estimates from the 2002 carcass survey data for the LFC. Logit P represents the response variable in the regression analysis, and corresponds to the logit transformation of P. Weight is the weight assigned to the response variable values calculated as the inverse of the estimated variance of P (Var. P).

The weighted least squares regression analyses for the 8 simple models indicated statistically significant linear relationships (*Pr(F)*<0.05) for all of the 8 independent variables. However, the amount of variation in the dependant variable accounted for by each independent variable varied considerably, as indicated by the corresponding coefficients of determination (*R Square*). The independent variable *Week* accounted for the highest percentage of variation (86.6 percent) in the dependent variable, followed by

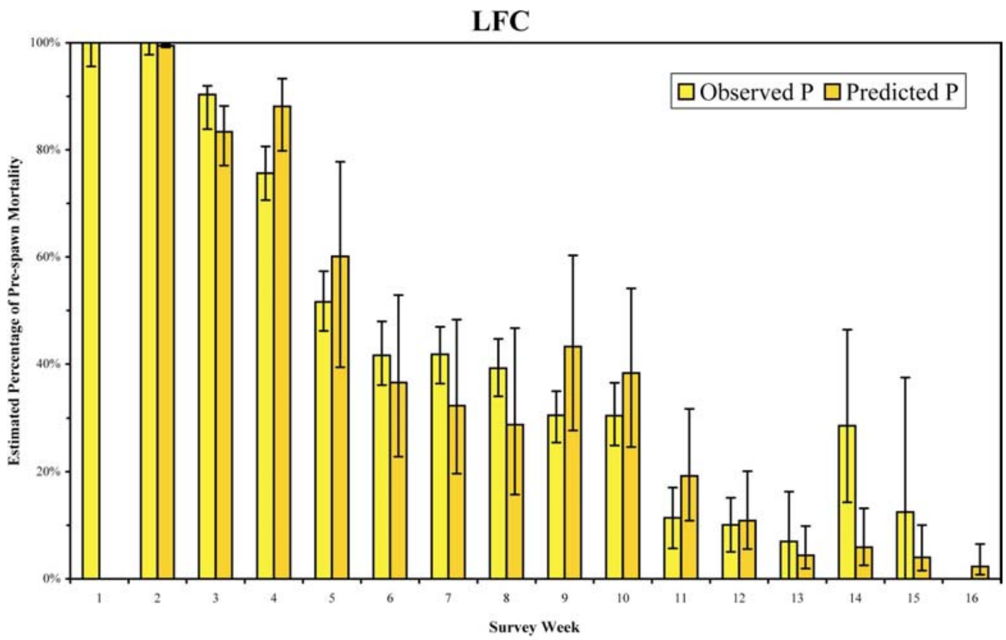
AT3 (79.8 percent), *AVarT2* (77.7 percent), *AT4* (70.5 percent), *Escapement* (46.1 percent), *AT2* (42.2 percent), *AVarT4* (35.5 percent), and *AVarT3* (27.2 percent). The *FM* model showed a statistically significant linear relationship (*Pr(F)*<0.05), and had a very high *R Square* value (0.988) indicating that this model accounts for 98.8 percent of the variation in pre-spawn mortality estimates in the LFC. However, it was undetermined if the regression coefficients for each of the 8 independent variables in the *FM* model were statistically different from zero (Pr(>|t|)>0.05), suggesting an over parameterized model. The stepwise model selection procedure chose the most parsimonious model, the *STM* model, which accounted for 98.2 percent of the variation in weekly pre-spawn estimates in the LFC. The three independent variables in the *STM* model (*Escapement, AVarT2, AT3*) were all statistically different from zero (Pr(>|t|)<0.05).

Table 5.11-5. The results from the weighted least squares regressions of the logit transformation of the 2002 weekly pre-spawn mortality estimates in the LFC.

MODEL	*Variable*	*Coefficient*	*Std. Error*	*t value*	*Pr(>|t|)*	*F Value*	*Pr(F)*	*R Square*
1	*(Intercept)*	5.8392	0.4502	12.97	0	84.336	0	0.866
	Week	-0.7292	0.0794	-9.1835	0			
2	*(Intercept)*	3.9467	0.7829	5.041	0	10.253	0.008	0.461
	Escapement	-0.0004	0.0001	-3.2021	0.008			
3	*(Intercept)*	-25.1282	9.0395	-2.7798	0.016	9.486	0.009	0.422
	AT2	2.0726	0.6729	3.08	0.009			
4	*(Intercept)*	-1.6224	0.7363	-2.2034	0.046	45.177	0	0.777
	AVarT2	3.6795	0.5474	6.7214	0			
5	*(Intercept)*	-26.7771	4.1253	-6.491	0	51.269	0	0.798
	AT3	2.0931	0.2923	7.1602	0			
6	*(Intercept)*	-0.2801	1.49	-0.188	0.854	4.854	0.046	0.272
	AVarT3	3.2088	1.4564	2.2032	0.046			
7	*(Intercept)*	-23.6052	4.7265	-4.9942	0	31.115	0	0.705
	AT4	1.841	0.33	5.5781	0			
8	*(Intercept)*	-1.3183	1.6119	-0.8179	0.428	7.163	0.019	0.355
	AVarT4	3.8289	1.4306	2.6764	0.019			
FM	*(Intercept)*	-40.005	44.8902	-0.8912	0.414	51.176	0	0.988
	Week	0.4025	1.1976	0.3361	0.75			
	Escapement	0.0002	0.0004	0.4428	0.676			
	AT2	0.9748	1.0409	0.9364	0.392			
	AVarT2	3.1334	3.0771	1.0183	0.355			
	AT3	1.1816	1.289	0.9167	0.401			
	AVarT3	1.4203	2.7154	0.5231	0.623			
	AT4	0.3353	1.2277	0.2732	0.796			
	AVarT4	0.9049	1.8131	0.4991	0.639			
STM	*(Intercept)*	-20.4665	2.4456	-8.3687	0	181.267	0	0.982
	Week	---						
	Escapement	0.0001	0	3.2422	0.009			
	AT2	---						
	AVarT2	2.7295	0.2626	10.394	0			
	AT3	1.3732	0.1762	7.7918	0			
	AVarT3	---						
	AT4	---						
	AVarT4	---						

The first eight models (1 through 8) represent simple linear models with independent variables AT2, AT3, AT4, AvarT2, AvarT3, AvarT4, Week, and Escapement. FM represents a multiple regression model that included all eight independent variables, and STM represents the reduced model selected by stepwise multiple regression.

The 2002 weekly pre-spawn mortality estimates predicted by the *STM* model in the LFC (using the independent variables *AVarT2*, *AT3*, and *Escapement*), the observed weekly pre-spawn mortality estimates in the LFC, and the corresponding 95 percent confidence intervals are shown in Figure 5.11-6. In general, the predicted and observed values were similar, with the 95 percent confidence intervals from the predicted estimates including and/or overlapping the 95 percent confidence intervals from the observed estimates. An exception to this was week 14 when the predicted estimate was much smaller than the observed estimate, which was likely due to the small weight calculated for week 14 in the regression analysis, which was a function of a small sample size and corresponding large variance for that survey week.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
From	9/3	9/9	9/16	9/23	9/30	10/7	10/14	10/21	10/28	11/4	11/11	11/18	11/25	12/2	12/9	12/16
To	9/5	9/12	9/19	9/26	10/4	10/10	10/17	10/25	10/31	11/8	11/14	11/21	11/27	12/5	12/11	12/19

Figure 5.11-6. The 2002 weekly pre-spawn mortality estimates predicted by the STM model in the LFC (using the independent variables AVarT2, AT3, and Escapement), the observed weekly pre-spawn mortality estimates in the LFC, and the corresponding 95% confidence intervals.

5.11.2.2 Pre-Spawn Mortality Regression Analyses in the HFC of the Lower Feather River

The variables used in the weighted regression analyses for the weekly pre-spawn mortality estimates in the HFC are shown in Table 5.11-6. The results from the weighted least squares regressions of the logit transformation of the weekly pre-spawn mortality estimates in the HFC are shown in Table 5.11-7.

Table 5.11-6. Variables used in the weighted regression analysis of the 2002 weekly pre-spawn mortality estimates in the HFC (P).

P	*Logit P*	*Var. P*	*Weight*	*Week*	*Escapemen*	*AT2*	*AVarT2*	*AT3*	*AVarT3*	*AT4*	*AVarT4*
1	3.0445	0.004	250	1	---	17.96	0.1575	19.54	6.0273	18.75	0.2355

1	3.6109	0.0012	842	2	378	18.63	0.2026	17.96	0.1575	19.54	6.0273
1	3.7136	0.001	962	3	1,431	16.64	0.1839	18.63	0.2026	17.96	0.1575
0.9583	3.1355	0.0016	618	4	1,066	16.65	0.2046	16.64	0.1839	18.63	0.2026
0.7222	0.9555	0.0111	90	5	1,766	16.25	0.1602	16.65	0.2046	16.64	0.1839
0.4138	-0.3483	0.0081	123	6	1,296	15.81	0.2577	16.25	0.1602	16.65	0.2046
0.4063	-0.3795	0.004	248	7	2,622	14.9	0.171	15.81	0.2577	16.25	0.1602
0.28	-0.9445	0.0027	373	8	3,145	15.6	0.1766	14.9	0.171	15.81	0.2577
0.2474	-1.1124	0.0019	538	9	2,723	15.28	0.1325	15.6	0.1766	14.9	0.171
0.194	-1.424	0.0011	892	10	5,046	14.87	0.056	15.28	0.1325	15.6	0.1766
0.1014	-2.1812	0.0006	1,549	11	5,045	13.72	0.0067	14.87	0.056	15.28	0.1325
0.1132	-2.0584	0.001	1,051	12	5,330	12.91	0.0063	13.72	0.0067	14.87	0.056
0.1471	-1.7579	0.0037	272	13	3,154	13.08	0.008	12.91	0.0063	13.72	0.0067
0.1875	-1.4663	0.0098	102	14	1,754	12.58	0.0042	13.08	0.008	12.91	0.0063
0.2	-1.3863	0.0305	33	15	755	11.39	0.0113	12.58	0.0042	13.08	0.008
---	---	---	---	16	153	11.55	0.0097	11.39	0.0113	12.58	0.0042

AT2, AT3, and AT4 represent the weekly averages of the mean daily water temperatures (oC) in the HFC, calculated 2, 3, and 4 weeks before the start of each survey sampling week. AvarT2, AvarT3, and AVarT4 represent the weekly averages of the mean daily water temperature variances (oC) in the HFC, calculated 2, 3, and 4 weeks before the start of each survey sampling week. Week represents the survey sampling week. Escapement represents the spawning escapement estimates from the 2002 carcass survey data for the HFC. Logit P represents the response variable in the regression analysis, and corresponds to the logit transformation of P. Weight is the weight assigned to the response variable values calculated as the inverse of the estimated variance of P (Var. P).

The weighted least squares regression analyses for the 8 simple models indicated statistically significant linear relationships (*Pr(F)*<0.05) for all but two of the 8 independent variables. The relationship between weekly pre-spawn mortality estimates, and the independent variables *AVarT3* and *AVarT4* was statistically not linear, as reflected by the low *R Square* values (0.069 and 0.252, respectively). The independent variable *Week* accounted for the highest percentage of variation (92.2 percent) in the dependent variable, followed by *AT4* (87 percent), *AT3* (82.2 percent), *AT2* (80.8 percent), *Escapement* (80.3 percent), and *AVarT2* (72.9 percent). The *FM* model showed a statistically significant linear relationship (*Pr(F)*<0.05), and had a very high *R Square* value (0.980), indicating that with the *FM* model, only 2 percent of the variation in pre-spawn mortality estimates in the HFC remained unexplained. However, it was undetermined whether or not the regression coefficients for the 8 independent variables in the *FM* model were statistically different from zero (Pr(>| t |)>0.05), suggesting an over parameterized model. The stepwise model selection procedure chose the most parsimonious model, the *STM* model. The *STM* model was the most appropriate of those tested, even though three of the five independent variables could not be determined to differ from zero, and accounted for 97.2 percent of the variation found in the weekly pre-spawn mortality estimates. The independent variables in the *STM* model that were statistically different from zero included *Escapement* and *AT4* (Pr(>| t |) = 0.002 and 0.016, respectively), and those that were not included *AT3*, *AVarT4*, and *AVarT3* (Pr(>| t |) = 0.057, 0.057, and 0.087, respectively).

Table 5.11-7. The results from the weighted least squares regressions of the logit transformation of the 2002 weekly pre-spawn mortality estimates in the HFC.

MODEL	Variable	Coefficient	Std. Error	t value	Pr(>|t|)	F Value	Pr(F)	R Square
1	*(Intercept)*	4.7808	0.4222	11.323	0	154.231	0	0.922
	Week	-0.5985	0.0482	-12.419	0			
2	*(Intercept)*	3.8189	0.6292	6.0691	0	48.848	0	0.803
	Escapement	-0.0012	0.0002	-6.9891	0			
3	*(Intercept)*	-18.3104	2.5107	-7.2929	0	54.573	0	0.808
	AT2	1.2097	0.1638	7.3874	0			

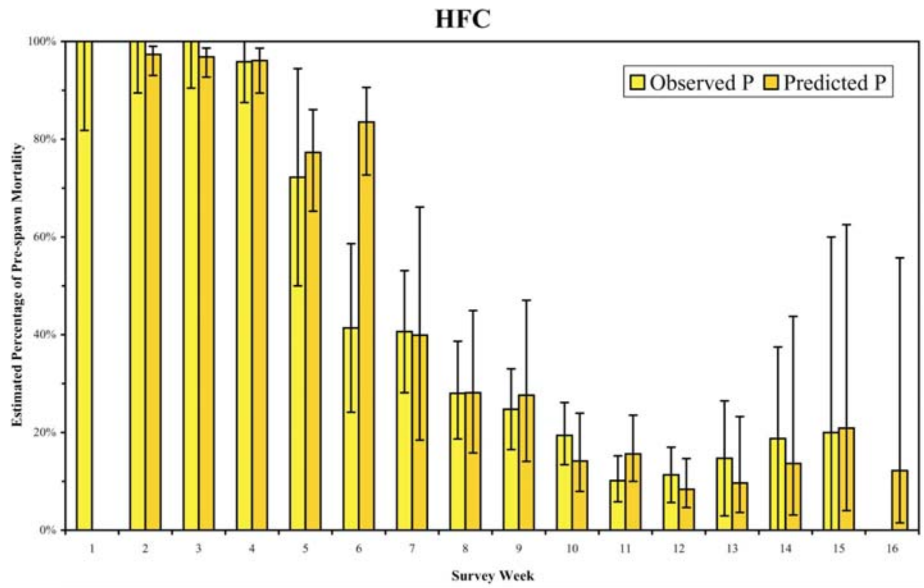
MODEL	Variable	Coefficient	Std. Error	t value	Pr(>|t|)	F Value	Pr(F)	R Square
4	*(Intercept)*	-2.398	0.553	-4.3366	0.001	35.019	0	0.729
	AVarT2	24.5678	4.1516	5.9177	0			
5	*(Intercept)*	-19.7384	2.5734	-7.6702	0	60.212	0	0.822
	AT3	1.2517	0.1613	7.7596	0			
6	*(Intercept)*	-0.0876	0.6889	-0.1272	0.901	0.967	0.343	0.069
	AVarT3	0.6285	0.6392	0.9833	0.343			
7	*(Intercept)*	-21.1709	2.2973	-9.2157	0	86.771	0	0.87
	AT4	1.2989	0.1394	9.3151	0			
8	*(Intercept)*	-0.4216	0.6436	-0.655	0.524	4.372	0.057	0.252
	AVarT4	0.6837	0.327	2.091	0.057			
FM	*(Intercept)*	8.1654	23.0068	0.3549	0.737	30.077	0.001	0.98
	Week	-0.7563	0.6526	-1.1589	0.299			
	Escapement	-0.0006	0.0003	-2.3456	0.066			
	AT2	0.2051	0.552	0.3716	0.725			
	AVarT2	-14.7629	11.6001	-1.2727	0.259			
	AT3	-0.1974	0.6102	-0.3235	0.759			
	AVarT3	-4.2881	7.1166	-0.6026	0.573			
	AT4	0.1308	0.6284	0.2082	0.843			
	AVarT4	-0.3294	0.2208	-1.4922	0.196			
STM	*(Intercept)*	-16.6445	2.9489	-5.6443	0	56.092	0	0.972
	Week	---						
	Escapement	-0.0006	0.0001	-4.4853	0.002			
	AT2	---						
	AVarT2	---						
	AT3	0.5249	0.2361	2.2232	0.057			
	AVarT3	-7.0508	3.6106	-1.9528	0.087			
	AT4	0.7052	0.2306	3.058	0.016			
	AVarT4	-0.2668	0.1202	-2.2194	0.057			

The first eight models (1 through 8) represent simple linear models with independent variables AT2, AT3, AT4, AvarT2, AvarT3, AvarT4, Week, and Escapement. FM represents a multiple regression model that included all eight independent variables, and STM represents the reduced model selected by stepwise multiple regression.

The 2002 weekly pre-spawn mortality estimates predicted by the *STM* model in the HFC (using the independent variables *Escapement*, *AT4, AT3*, *AVarT4*, and *AVar3)*, the observed weekly pre-spawn mortality estimates in the HFC, and the corresponding 95 percent confidence intervals are shown in Figure 5.11-7. In general, the predicted and observed values were similar, with the 95 percent confidence intervals from the predicted estimates including and/or overlapping the 95 percent confidence intervals from the observed estimates. An exception to this was week 6, when the predicted estimate was much larger than the observed estimate, which was likely due to the small weight calculated for survey week 6 in the regression analysis, which was a function of a small sample size and corresponding large variance for that survey week.

5.12 REDD SUPERIMPOSITION

The redd superimposition results reported for the 1995 spawning season were taken directly from Sommer et al. (2001). In 1995 in the LFC, the area disturbed by spawning Chinook salmon equaled 773,732 ft^2, with the greatest area concentrated in the upper couple of miles. The upper-most three miles of the LFC contained more than 60 percent of the defined spawning area. The majority of spawning occurred in riffles and glides. The adult Chinook salmon spawning escapement estimate in 1995 in the LFC was 44,111. The estimated superimposition index in the LFC was 1.57. In 1995 in the HFC, the area disturbed by spawning Chinook salmon equaled 915,089 ft^2. Areas used for spawning were evenly distributed throughout the HFC, with glide areas showing the highest use. The adult Chinook salmon spawning escapement estimate in the HFC during 1995 was 15,572, with an estimated superimposition index of 0.47.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
From	9/3	9/9	9/16	9/23	9/30	10/7	10/14	10/21	10/28	11/4	11/11	11/18	11/25	12/2	12/9	12/16
To	9/5	9/12	9/19	9/26	10/4	10/10	10/17	10/25	10/31	11/8	11/14	11/21	11/27	12/5	12/11	12/19

Figure 5.11-7. The 2002 weekly pre-spawning mortality estimates predicted by the STM model in the HFC (using the independent variables Escapement, AT4, AT3, AVarT4, and AVar3), the observed weekly pre-spawn mortality estimates in the HFC, and the corresponding 95% confidence levels.

The areas disturbed by spawning Chinook salmon in 2003 are shown in Figure C2 through Figure C11 (Appendix C). In 2003 in the LFC, the area disturbed by spawning Chinook salmon equaled 509,384 ft^2, with a large area concentrated near the hatchery. The upper-most 1.5 miles of the lower Feather River contained more than 40% (42%, 212,178 ft^2) of the defined spawning area within the LFC. The majority of spawning occurred in riffles and glides. The spawning escapement estimate in 2003 in the LFC was 58,468. The estimated superimposition index in the LFC was 3.16 when 0.5 was used as the sex ratio variable, and 2.28 when 0.36 was used as the sex ratio variable. The superimposition indices are higher than those reported for 1995. In 2003 in the HFC, the area disturbed by spawning Chinook salmon equaled 688,361 ft^2. Areas used for spawning were evenly distributed throughout the HFC, with the majority of spawning occurring in riffles and glides. The spawning escapement estimate in 2003 in the HFC was 39,600. The estimated superimposition index in the HFC was 1.58 when 0.5 was used as the sex ratio variable, and 1.54 when 0.49 was used as the sex ratio variable. The superimposition indices are higher than those reported for 1995. The variables used in the superimposition index equation, and the corresponding superimposition indices, for 1995 and 2003 are summarized in Table 5.12-1.

Table 5.12-1. Variables used to determine the superimposition index values in the lower Feather River, by reach, for 1995 and 2003. The superimposition index values are also provided.

<table>
<tr><th>Year</th><th>Reach</th><th>Escapement Estimate</th><th>Spawning Area ft2</th><th>Sex Ratio</th><th>Redd Area ft2</th><th>Superimposition Index</th></tr>
<tr><td rowspan="2">1995</td><td>LFC</td><td>44,111</td><td>773,732</td><td rowspan="2">0.50</td><td rowspan="6">55.0</td><td>1.57</td></tr>
<tr><td>HFC</td><td>15,572</td><td>915,089</td><td>0.47</td></tr>
<tr><td rowspan="4">2003</td><td rowspan="2">LFC</td><td rowspan="2">58,468</td><td rowspan="2">509,384</td><td>0.36</td><td>2.28</td></tr>
<tr><td>0.50</td><td>3.16</td></tr>
<tr><td rowspan="2">HFC</td><td rowspan="2">39,600</td><td rowspan="2">688,361</td><td>0.49</td><td>1.54</td></tr>
<tr><td>0.50</td><td>1.58</td></tr>
</table>

6.0 ANALYSES

6.1 WATER TEMPERATURES IN THE LOWER FEATHER RIVER, AND ASSOCIATED EFFECTS TO SPAWNING CHINOOK SALMON

The spawning cycle of adult Chinook salmon consists of multiple stages, including adult migration and holding, spawning activities, construction of redds, egg and embryo incubation, and residence time on redds. Response to, and the effects from, water temperature for each stage vary. The discussion in this report will focus on the effects of water temperatures on adult Chinook salmon while on the spawning grounds. The effects on incubating eggs and alevins are specifically addressed in SP-F10 Task 2A "*Evaluate spawning and incubation substrate availability and suitability for salmonids in the Feather River*."

Daily maximum, mean, and minimum water temperature data were collected at multiple locations in the lower Feather River. When analysis of water temperatures and carcass distribution was performed, water temperature data were available only for the 2002 spawning period. Daily maximum and minimum water temperatures are a single data point, and do not persist throughout a diel cycle. Reportedly, the effects from thermal stress are positively correlated with exposure times. Therefore, mean daily water temperature may be the most appropriate variable with which to gauge potential effects from thermal stress. In general, mean daily water temperatures in the lower Feather River were suitable for spawning Chinook salmon. During the defined spawning period, water temperatures in the LFC were cooler than water temperatures in the HFC, particularly during mid-August through September.

6.1.1 Water Temperatures in the Low Flow Channel of the Lower Feather River, and Associated Effects to Spawning Chinook Salmon

Mean daily water temperatures in the LFC, during the defined spawning period (August 12 through December 19), rarely exceeded 60°F (15.6°C). McCullough (1999) reported that at temperatures above 60.8°F (16°C) spawning likely does not occur. Others have reported that when water temperatures decline to 60°F (15.6°C) and continue to decline, spawning activities are initiated (Chambers 1956; Dauble and Watson 1997; Groves and Chandler 1999). Water temperatures in the LFC do not appear to influence the spawn timing of Chinook salmon in the lower Feather River. Marine (1992) reported that water temperatures between 42.8-57.2°F (6-14°C) were optimal for pre-spawning brood stock survival. Water temperatures in the LFC in August exceeded 58°F (14.4°C), which may adversely affect adults and other life stages of the spawning and embryo incubation cycle. NOAA Fisheries (1997) stated that reduced egg viability and significant egg mortality occurs at temperatures in excess of 57.5°F (14.2°C). Boles (1988), citing Brett (1952), Seymour (1956), and Hinze (1959), reported that the highest survival has been found in Chinook salmon eggs from fish from the Sacramento River when incubated at temperatures ranging from 53 to 57.5°F (11.7-14.2°C). McCullough (1999) reported that when ripe females are exposed to water temperatures above approximately 57.2°F (14°C), latent effects to alevins might occur in the form of poor development. Water temperatures in the LFC from September through December (except a few days in October), did not exceed 56°F (13.3°C). Water temperatures below 56°F are generally regarded as desirable during the spawning and embryo incubation life stage. In general, water temperatures in the LFC of the lower Feather River appear to be conducive during the spawning and embryo incubation life stage of Chinook salmon.

6.1.2 Water Temperatures in the High Flow Channel of the Lower Feather River, and Associated Effects on Spawning Chinook Salmon

The defined spawning period in the lower Feather River, based on carcass survey data, was August 12 through December 19. However, these dates may be under- or over-estimated because carcasses were found on the first and last days of the carcass surveys. Mean daily water temperatures in the HFC remained below 56°F (13.3°C) from November through December. Water temperatures below 56°F are generally regarded as acceptable during the spawning and embryo incubation life stage. Mean daily water temperatures exceeded 64°F (17.8°C) in August and 62°F through mid September. Agreement exists within available literature that significant mortalities of eggs and alevin occur at water temperatures above 62°F (16.7°C). The Salmon Mortality Model (U.S.Bureau of Reclaimation 2004), developed by USBR and applied primarily to Central Valley systems, factors in 100 percent mortality of fertilized Chinook salmon eggs after 12 days of exposure to 62°F water (16.7°C), 100 percent mortality of fertilized eggs after 7 days of exposure to 64°F (17.8°C) water, and 100 percent mortality of alevins after 10 days of exposure to 64°F water. USFWS (1999) stated that incubation temperatures of 62 to 64°F appear to be the physiological limit for embryo development resulting in 80-100 percent mortality prior to emergence. Seymour (1956), and Johnson and Brice (1953) also reported high egg and alevin mortalities associated with water temperatures above 62°F. As suggested by McCullough (1999), residual effects may occur during other life stages when ripe females are exposed to such high water temperatures. Mean daily water temperatures in the HFC, from August through late September, may be cause for concern. Moyle (2002) reported that spring-run Chinook salmon in the Central Valley of California spawn from late August through October, with peak spawning occurring in mid-September. High water temperatures in the HFC during the beginning of the spawning period for Chinook salmon may impact the spring-run to a greater degree than the fall-run because of temporal differences in spawn timing. Although the genetic identity of early spawners in the lower Feather River is questionable, early spawners may represent federally threatened Central Valley ESU spring-run Chinook salmon. Pre-spawn mortality rates in the lower Feather River, from September through early October, were high during the 2000, 2001, 2002, and 2003 carcass surveys, particularly in the HFC where estimates sometimes were 100 percent. Pre-spawn mortality estimates were generally negatively correlated with time, showing decreases in both reaches as the carcass surveys progressed. In general, water temperatures also decreased with time. High water temperatures may be the cause of high pre-spawn mortality of Chinook salmon in the lower Feather River, but little is known about pre-spawn mortality, and there are likely many contributing factors. Assuming that high water temperatures account for most of the pre-spawn mortality, changing the Oroville Facilities operational procedures to alleviate the problem might be ineffective because the projects' ability to manipulate water temperature, through flow release, decreases with downstream distance from Oroville Dam. The 2002 carcass survey found that in the HFC, in general, pre-spawn mortality was positively correlated with distance downstream. Pre-spawn mortality estimates in the HFC are high, and high water temperature may be the cause, but the impacts may not be as significant as the empirical results suggest. The high estimates were based on small sample sizes, and estimates may not represent the true population parameter. Fewer Chinook salmon spawn in the HFC than in the LFC. Escapement estimates, based on carcass survey data from 2000 through 2003, suggest that only 38 percent of the spawning Chinook salmon population in the lower Feather River spawn in the HFC. Pre-spawn mortality estimates also were high in the LFC, during periods when water temperatures were within acceptable water temperature ranges, suggesting that water temperature may be only partially responsible for pre-spawn mortalities.

6.2 CHINOOK SALMON CWT SURVEY

The results from the CWT surveys provide information pertaining to the spatial and temporal distribution of spawning Chinook salmon known to be of hatchery origin. Interpretation of spatial spawning distributions based on carcass surveys assumes that, in general, salmon spawn in proximity to the location of carcass detection. CWT programs provide information on wild fish only to the extent that the proportion of hatchery produced individuals returning can be calculated from the known fractional proportion that was tagged prior to release. Because only a small proportion of hatchery fish generally are tagged, however, estimating the composition of the spawning population from tags is problematic. For example, from 1995 through 2001, it was reported that approximately 15 percent of hatchery fish released by DFG were implanted with CWTs (pers. comm., A. Kastner, 2003). During the 2000 through 2003 CWT surveys, 5.6 percent of inspected Chinook salmon carcasses in the lower Feather River had a clipped adipose fin. The highest percentages of adipose fin clipped fish, from 2000 through 2003, were generally found in September in the LFC. The temporal and spatial distribution remained consistent through all study years. The analyses for the 2002 carcass survey provided finer scale spatial distributions. The results from October are likely the best representation of this distribution because of the larger sample sizes. High numbers of carcasses with a clipped adipose fin were detected within approximately one mile of the Feather River Hatchery. Many potential explanations exist for the temporal and spatial distributions of spawning Chinook salmon known to be of hatchery origin in the lower Feather River. Factors responsible for these distributions include spawning habitat quality and quantity, water temperature, run composition, and hatchery practices. Operational procedures of the Feather River Hatchery may have the most influence on when and where hatchery reared Chinook salmon spawn. Sommer et al. (2001) reported that since the construction of Oroville Dam and the Feather River Hatchery, Chinook salmon have shifted spawning activities from predominantly in the reach below Thermalito Afterbay Outlet to the LFC. An average of 75 percent of spawning activity occurred in the LFC, with the greatest portion crowded in the upper three miles of the LFC. Prior to 1983, most juvenile Chinook salmon reared at the Feather River Hatchery were released in the Feather River, but after 1983, most were released in the Sacramento-San Joaquin Estuary (Sommer et al. 2001). The change in hatchery procedures may have increased survival rates of hatchery Chinook salmon, leading to higher escapement and an increased proportion of hatchery fish in the spawning population in the lower Feather River. Salmon of hatchery origin are likely to have a stronger affinity to spawn in those riffles closest to the hatchery than are wild fish (Sommer et al. 2001), and this characteristic could account for the spatial distribution of spawning hatchery fish in the lower Feather River. Reynolds (1993) reported that the Feather River Hatchery is the only source of spring-run Chinook salmon eggs in the Central Valley. Although the genetic identity of spring-run Chinook salmon in the Feather River is questionable, the Feather River Hatchery may select the earliest arriving fish for spring-run broodstock. Spring-run Chinook salmon spawn earlier than fall-run Chinook salmon, and this characteristic could account for the temporal distribution of spawning hatchery fish in the lower Feather River.

The information acquired from decoding the CWTs from the 2002 survey is located in Tables 5.5-1 and 5.5-2. The heads from 439 carcasses having a clipped adipose fin were processed, and 350 (80.8 percent) contained a CWT (Table 5.5-1). Six of the salmon heads were not processed. Most of the processed carcasses were determined to have originated from Feather River stock (96.6 percent), and were released from the Feather River Hatchery or by other hatcheries. The straying rate into the Feather River of Chinook salmon originating from non-Feather River stock was 3.4 percent. The 2002 CWT sample consisted of 206 (60.9 percent) salmon that were released as fall-run Chinook salmon, and 132 (39.1 percent) that were released as spring-run Chinook salmon (Table 5.5-2). The greatest percentage (60.2 percent) of carcasses that were released as fall-run Chinook salmon were recovered during week 5 through 7 (September 30 through October 17). The greatest percentage (53 percent) of carcasses that were released as spring-run Chinook salmon were recovered during week 3 and 4 (September 16 through September 26). Overlap in carcass recovery week between fall-run and spring-run Chinook salmon occurred during week 1 through week 7 (September 3 through October 17), and was most significant during week 4 through 6 (September 23 through October 10). The greatest percentage of carcasses that were released as fall-run Chinook salmon were aged 3 (42.7 percent) and 4 years old (48.1 percent). The greatest percentage of carcasses that were released as spring-run Chinook salmon were aged 3 (18.2 percent) and 4 (74.2 percent) years old.

During the 2002 CWT survey, the heads from 439 carcasses having a clipped adipose fin were retained and processed, and 350 (80.8 percent) contained a CWT. A very high percentage of these fish (96.6 percent) originated from Feather River stock. Salmon from the Feather River have been documented as straying throughout the Central Valley (Dettman and Kelley 1987), however, the results from the 2002 CWT survey only document straying rates of fish originating from other systems into the Feather River. Straying is of concern because of the potentially negative effects on the genetic distinctiveness of Chinook salmon populations, and the potential to reduce the genetic variability of wild Central Valley Chinook salmon. The potentially negative effects from strays into the Feather River is of particular concern because the Feather River is one of the few systems in the Sacramento-San Joaquin system that maintains a sizeable return of federally threatened spring-run Chinook salmon. The 3.4 percent straying rate into the Feather River is low when compared to other studies. Quinn et al. (1991) reported an estimated 9.9 percent straying rate of hatchery Chinook salmon from the Lewis River, and an estimated range of 1.4-28.5 percent straying rate of hatchery Chinook salmon from the Cowlitz River in Washington. Straying may be influenced by many factors, but hatchery procedures likely are the most influential. Cramer (1990) suggested that straying has dramatically increased since hatchery fish have been trucked to estuaries and not released in river. Previous straying analysis of Feather River Hatchery Chinook salmon has shown that when fish were released in the Feather River, the mean straying rate (number of strays/freshwater escapement) was estimated to be 7.3 percent, with upper and lower 95 percent confidence limits of 0.6 percent and 20.5 percent. The mean straying rate for Feather River Hatchery Chinook salmon released in the estuary was estimated to be 69.1 percent, with upper and lower 95 percent confidence limits of 55.7 percent and 81.0 percent (Cramer 1990). Similar results were reported by Dettman and Kelley (1987). The straying rates of Chinook salmon into the Feather River are low, but it is important to note that this conclusion is based on one year of data.

The 2002 CWT sample consisted of 206 (60.9 percent) salmon that were released as fall-run Chinook salmon, and 132 (39.1 percent) that were released as spring-run Chinook salmon (Table 5.5-2). The highest percentages of salmon were recovered during times agreeing with their designated run of origin. However, there was significant overlap from September 3 through October 17. Brown and Greene (1994) also reported that significant portions of the offspring of each hatchery race returned as adults during the wrong period, and that many of the designated spring-run fish returned during months when hatchery operators designated all spawners as fall-run. The Feather River Hatchery designates all adult salmon arriving up to October 1 as spring-run Chinook salmon, and all fish arriving after October 1 as fall-run Chinook salmon (DFG 1998b). The operational procedures of the Feather River Hatchery that are designed to maintain genetic isolation between spring-run and fall-run Chinook salmon appears to be ineffective. Even low rates of annual genetic introgression can have significant impacts because the problem compounds with each passing year. The cumulative effects could eliminate reproductive isolation between runs. Many authors question the current genetic integrity of spring-run Chinook salmon in the Feather River (Hedgecock et al. 2001). Under current operational procedures, the Feather River Hatchery may contribute to the genetic erosion and introgression of the spring-run Chinook salmon in the lower Feather River.

6.3 DISTRIBUTION OF CHINOOK SALMON CARCASS COUNTS

In 2002, carcass survey results indicated that 81.1 percent of carcasses were detected in the LFC. Sommer et al. (2001) reported similar results. In general, water temperatures in the LFC are cooler, which may account for the higher number of spawners in the LFC. Mean daily water temperature in the HFC decreased at the end of October (Figure 5.3-1), and by November 1 dropped below 56°F (13.3°C) and was very similar to water temperatures in the LFC. During the same period, the number of carcasses detected in the LFC decreased while the number of carcasses detected in the HFC increased (Figure 5.6-1). Initially, this appears to support water temperature as a descriptor of the disproportionate number of carcasses detected in the LFC from August through the beginning of November. However, the argument assumes that carcasses are detected relatively soon after a fish spawns so that water temperatures are reflective of the appropriate spawning date. As previously discussed, the lag in time between spawning initiation and carcass detection is approximately three weeks. Water temperatures in the lower Feather River can fluctuate widely in three weeks. Available spawning habitat may also account for the variability in the spatial distribution of carcasses in the lower Feather River. Sommer et al. (2001) documented spawning distributions, analyzed spawning gravel data from 1982 and 1996, and described the temporal and spatial trend in gravel characteristics in the LFC and the HFC. The study documented a marked shift in the spawning distribution of Chinook salmon in the lower Feather River. Since the construction of Oroville Dam and the Feather River Hatchery, salmon have shifted their spawning activity from predominantly in the HFC to the LFC. Results also indicated that mean gravel sizes were larger in the LFC, and that through time gravels are becoming larger in the LFC. The temporal change in gravel size in the LFC suggests armoring is occurring due to decreased recruitment of smaller gravel sizes. Based on the results from Sommer et al. (2001), it is unlikely that spawning habitat characteristics account for carcass distributions because gravel suitability and the number of spawners is negatively correlated, the exact opposite of what would be expected. The disproportionate use of the LFC by spawning Chinook salmon is most likely the result of hatchery operations. Mean escapement estimates, and stability across years, have increased since hatchery operations began (Figure 2.6-1 and Figure 2.6-2). Prior to 1983, most hatchery-reared juvenile Chinook salmon were released in the lower Feather River, but after 1983, most were released in the Sacramento-San Joaquin Estuary. The change in release location may have increased survivability causing a disproportionate increase in return rates of hatchery-reared Chinook salmon. Salmon of hatchery origin are likely to have a stronger behavioral attraction to spawning locations adjacent to the Feather River Hatchery, which is located in the upper portion of the LFC (Sommer et al. 2001). An alternative hypothesis is that genetic introgression between fall-run and spring-run Chinook salmon increased spawning in the LFC. Genetic integrity for these two races historically has been maintained by differences in spawn timing and spawning locations. Dam construction has blocked spring-run access to traditional spawning locations, causing a proportionately higher overlap in spawning sites. In an attempt to maintain genetic separation, hatchery operators designate the early arrivals as spring-run. However, this approach does not appear to have been successful (Sommer et al. 2001). Brown and Greene (1994) described coded-wire tag studies on the progeny of hatchery fish identified as fall-run and spring-run, and found evidence of substantial introgression. Brown and Greene (1994) reported that significant portions of the offspring of each hatchery race returned as adults during the wrong period. For example, many of the spring-run group returned during months when hatchery operators designated all spawners as fall-run. Based on historical spawning behavior, gradual introgression of spring-run traits into the Feather River Chinook salmon population would be expected to result in an increasing preference to spawn in the uppermost riffles of the LFC.

The 2002 temporal distribution of spawning Chinook salmon in the lower Feather River is shown in Figure 5.6-1. The number of salmon spawning in the LFC and the HFC peaked from October 7 through October 31, and from November 4 through November 27, respectively. The peak spawning dates represent the latest possible dates because the estimates were based on carcass detection dates, and up to three weeks may elapse between spawning initiation and carcass detection. Adjusting for this lag in time, peak spawning dates in the LFC and HFC may have occurred as early as September 16 through October 10, and October 14 through November 6, respectively. The true peaks in spawning densities likely fall somewhere between the two sets of estimates. Temporal distributions may be a function of water temperature. Several studies have concluded that spawning activities are initiated when water temperatures are near 60^{o}F (15.6^{o}C) and accompanied by a decreasing water temperature trend (Dauble and Watson 1997; Groves and Chandler 1999). Spawning likely began sometime between August 12 and September 3 (the first carcass detected was on September 2). During this period, mean daily water temperatures in the LFC ranged from 55 to 61.8^{o}F (12.8-16.6^{o} C), and averaged 58.3^{o}F (14.6^{o}C) with no clear decreasing or increasing trend. During this period, mean daily water temperatures in the HFC ranged from 61.5 to 68.6^{o}F (16.4-20.3^{o}C), and averaged 65.4^{o}F (18.6^{o}C) with no clear decreasing or increasing trend. During the peak spawning period in the LFC (September 16 through October 31, which includes the range of possible dates), mean daily water temperatures ranged from 51.9 to 57^{o}F (11.1-13.9^{o}C), and averaged 55^{o}F (12.8^{o}C) with a slightly increasing trend. During the peak spawning period in the HFC (October 14 through November 27, which includes the range of possible dates), mean daily water temperatures ranged from 52.3 to 59.7^{o}F (11.3-15.4^{o}C), and averaged 56.3^{o}F (13.5^{o}C) with a decreasing trend. The water temperature profiles in the LFC and HFC were very similar during respective peaks in spawning densities, and were close to values reported from other studies (Dauble and Watson 1997; Groves and Chandler 1999).

6.4 SPAWNING ESCAPEMENT ESTIMATES

In general, the temporal and spatial distributions of escapement estimates mirror the temporal and spatial distributions of carcass counts. The numbers of carcasses counted are proportional to escapement estimates. The focus of this section will be on annual variation in estimate totals.

Survival at each life stage influences the number of spawners that eventually return to spawn. The physical and environmental factors responsible for survival are numerous, and likely include relationships that currently are poorly understood. During the life cycle of Chinook salmon, there are three distinct periods of survival: freshwater residence lasting from the egg stage through saltwater entry, ocean residence, and adult return to natal spawning areas. The least understood, and possibly the most influential and complex life stage, is the period that salmon spend maturing and growing in the ocean. Analyses of the CWTs collected during the 2002 CWT survey indicated that most Feather River Chinook salmon spend between 3 and 4 years in the ocean (81.2 percent). Thus, escapement totals are influenced by ocean conditions in each of the 3 to 4 years prior to adult return, river conditions 3 or 4 years prior to adult return (emigration), and river conditions during adult upstream migration and holding.

Escapement estimates in the lower Feather River for 2001 were much higher, in both reaches, than in the other survey years (2000, 2002, 2003). The differences may be due to disproportionate survey effort, or due to physical and environmental conditions between 1997 and 2001, both in the ocean and river, being more conducive to survival. Inconsistent annual hatchery operations may also account for the high Chinook salmon returns to the lower Feather River in 2001. The escapement estimates from 2000 through 2003 are much higher than the mean escapement estimates from post-Oroville Dam construction 1968 through 1994, and from pre-Oroville Dam construction 1953 through 1967 (Figure 2.6-1 and Figure 2.6-2). Escapement estimates from 2000 through 2003 also are much higher than the previous highest escapement estimate of approximately 87,000 in 1954. The higher estimates may reflect more successful techniques used by the Feather River Hatchery, or better management of instream conditions (i.e., manipulation of water temperature and flow). However, the 2000 through 2003 escapement estimates exceed historical estimates by such a large margin that it is unlikely that physical and environmental conditions, both in freshwater and in the ocean, and more efficient hatchery operations could account for the magnitude of increase. The differences are most likely the result of different methodologies used to calculate estimates, or due to unequal sampling effort between years.

6.5 INSTREAM FLOW AND SPAWNING HABITAT AVAILABILITY

Used appropriately, IFIM, PHABSIM, and WUA are useful decision-support tools designed to help natural resource managers determine the benefits or consequences of different water management alternatives. For this study, the PHABSIM modeling approach was used to evaluate how flow affects the amount of available spawning habitat in the lower Feather River. The WUA index, also known as a relative suitability index (RSI; (Payne 2003), relates the extent of match between hydraulics and habitat suitability for flows specified in the models. The index is only a relative indicator of suitability, not actual physical area, and cannot be directly related to numbers of fish that may occupy the Feather River at the modeled flows. The index does provide the capacity to compare various flow regimes, however, for evaluating the suitability of alternatives. The flow/habitat availability curve (Figure 5.10-1), generated using PHABSIM methodology, depicting instream flow and the corresponding WUA index for Chinook salmon spawning habitat in the LFC, predicted that the maximum amount of spawning habitat would be available at river flows between 700 and 725 cfs. In general, flows in the LFC are maintained at 600 cfs year round. Based on the flow/habitat availability curve, the differences in the WUA index between 600 cfs and 725 cfs is small. The WUA index value for flows in the LFC, maintained through releases by the Oroville facilities, during the Chinook salmon spawning period are approximately 97 percent of the maximum WUA index value (Figure 6.5-1). The flow/habitat availability curve for the HFC predicted that the maximum amount of spawning habitat would be available at a flow of 1500 cfs (Figure 5.10-2), slightly more than twice the flow corresponding with the maximum index value in the LFC. From 2000 through 2002, flows in the HFC during the Chinook salmon spawning period ranged from 1,200-5,000 cfs (Figure 2-1) corresponding with approximately 40-95 percent of the maximum WUA index value, respectively (Figure 6.5-2). During the period that most carcasses were detected, flows in the HFC ranged from 2,450 (2000) to 1,200 (2001) cfs corresponding to approximately 84-97 percent of the maximum WUA index values, respectively.

Sommer et al. (2001) conducted similar PHABSIM analyses in the lower Feather River. The modeling results predicted that the WUA index, and corresponding spawning habitat availability, would be maximized in the LFC at a flow of 1,000 cfs, and in the HFC at a flow of 3,250 cfs. The models developed for SP-F10 Task 2B predicted that in the LFC at 1000 cfs, approximately 88 percent of the maximum spawning habitat index would be available (Figure 6.5-1). In the HFC at 3,250 cfs, approximately 66 percent of the maximum spawning habitat index would be available (Figure 6.5-2).

In general, flows in the lower Feather River, from 2000 through 2002, during the Chinook salmon spawning period provide for a high percentage of the theoretical maximum amount of spawning habitat, particularly in the LFC. Flows in the HFC could be manipulated to provide more spawning habitat than has been available in recent years. The flows in the lower Feather River appear to provide acceptable amounts of spawning habitat, compared to the theoretical maximum amount of available habitat. However, it is important to note that these conclusions assume that carcass detection dates represent spawning dates. The carcass survey data only revealed when carcasses were discovered, and do not account for the time that elapsed between the initiation of spawning activity and discovery of carcass. In this report, three weeks was used as an adjustment to offset the lag in time between redd construction and carcass detection, but the defined spawning period is still an estimate. A higher amount of spawning habitat in the HFC could be provided through flow manipulation based on the estimated beginning of the spawning period and the corresponding river flows. In general, flows in the HFC are relatively high during the month of August when Chinook salmon begin spawning. The amount of available habitat during this period, when compared to the theoretical maximum amount possible, is relatively low. Decreasing flows in the HFC earlier could potentially alleviate stress loading associated with habitat availability, and this may benefit the earlier spawning spring-run Chinook salmon.

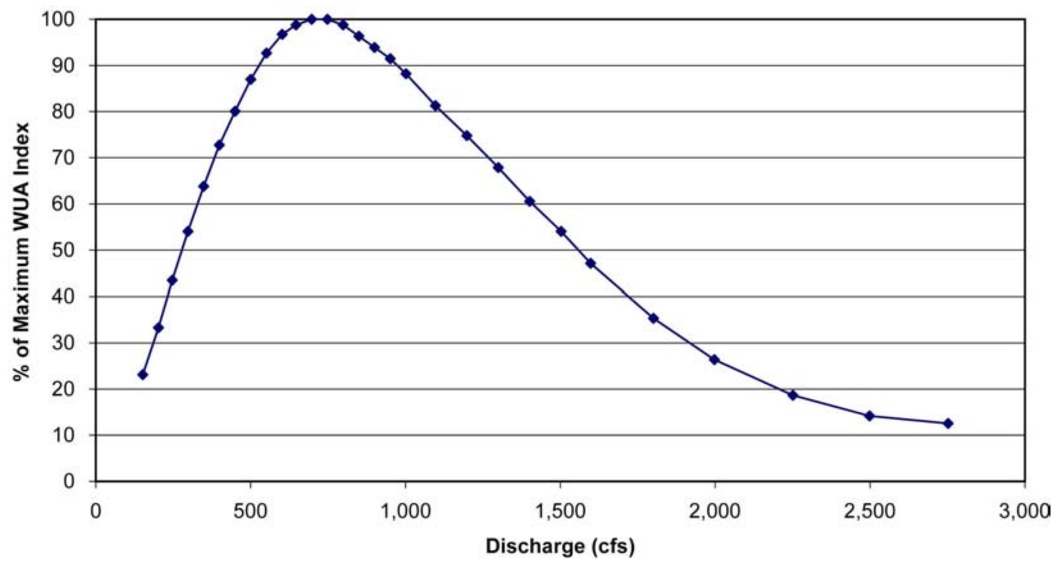


Figure 6.5-1. The percentage of the maximum WUA Index provided at various instream flows in the LFC of the lower Feather River.

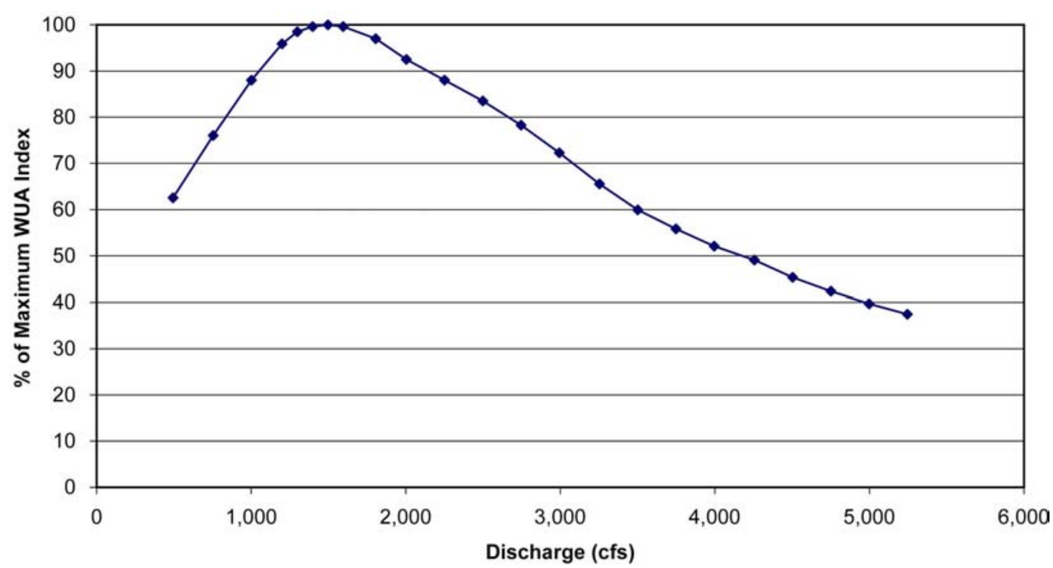


Figure 6.5-2. The percentage of the maximum WUA Index provided at various instream flows in the HFC of the lower Feather River.

6.6 PRE-SPAWN MORTALITY

Pre-spawn mortality estimates in the lower Feather River from 2000 through 2003 were high when compared to reported estimates from some other systems. Observer bias may account for a small fraction of the high estimates because of the subjective nature of the protocol, however there are likely other contributing factors. In 1988, DFG reported that in the Trinity River pre-spawn mortality ranged from a high of 75 percent at the beginning of the spawn, to a low of 23 percent in the final weeks (Zuspan et al. 1991). The overall female Chinook salmon pre-spawning mortality rate during the survey period was 44.9 percent. The percentage of females that died prior to spawning in the American River reportedly ranged from 3 percent in 1993 to 19 percent in 1995

(Williams 2001). Pre-spawn mortality rates reportedly were 60 percent and 87 percent on Battle Creek in 2002 and 2003, respectively (pers. comm., C. Harvey-Arrison, 2004). In the lower American River, 2003 pre-spawn mortality reportedly was at least 37 percent, and could possibly be higher if partially spawned fish are included (Healey 2004). Pre-spawn morality in the Yuba River, however, was reported to be less than 4 percent in 2003 (pers. comm., S. Theis, 2004). T. Heyne (2004) reported that pre-spawn mortality rates in tributaries to the San Joaquin River (Tuolumne, Stanislas, and Merced rivers) typically are 5 percent or less. In the Sacramento River, pre-spawn mortality for fall and late-fall-run Chinook salmon were as high as 13 percent in 1996, but was between 3 percent and 8 percent in other years (Snider et al. 1999; Snider et al. 2000). From 2000 through 2003, the pre-spawn mortality estimate in the LFC and HFC averaged approximately 42.5 and 39.7 percent, respectively. The average pre-spawn mortality rate combining all study years and both reaches was approximately 41.1 percent. For all years and both reaches, 70-100 percent of carcasses inspected in the first four weeks (September 2 through October 4) were determined to have died prior to spawning. The high estimates during the beginning of the spawning period are of particular concern because federally threatened CV ESU spring-run Chinook salmon may contribute to the initial spawners. The Feather River Hatchery designates all adult salmon arriving up to October 1 as spring-run Chinook salmon, and all fish arriving after October 1 as fall-run Chinook salmon (DFG 1998b). The general belief is that hatchery fish are less genetically fit, and are more susceptible to stressors than are wild fish (Reisenbichler and McIntyre 1977, as cited by McCullough 1999). If this is the case, then it may be that most of the pre-spawn mortality in September in the lower Feather River is attributable to the less resistant hatchery spring-run Chinook salmon. In 2000, 2001, 2002, and 2003, the percentage of inspected carcasses that had an adipose fin clip was approximately 3.1 percent, 4.7 percent, 7.9 percent, and 6.8 percent, respectively. For all years combined, the percentage of inspected carcasses that had an adipose fin clip was 5.6 percent. The percentage of inspected carcasses that had and adipose fin clip in September in 2000, 2001, 2002, and 2003 was approximately 9.2, 12.5, 16.3 percent, and 12.4 percent, respectively. The Feather River Hatchery does not clip all hatchery reared Chinook salmon released into the lower Feather River. The origin of non-clipped salmon is therefore uncertain. Hankin (1982) suggested implementation of several hatchery practices that would allow the discrimination of wild and hatchery fish, most notably for hatcheries to distinctly mark a constant proportion of releases from year to year. Hankin (1982) stated that annual variation in marking proportions rules out later discrimination between returns of hatchery and wild fish. Data from the Feather River Hatchery concerning the proportion of releases distinctly marked were unavailable, but it is unlikely the proportions were constant during those years that would affect the results from this study. Therefore, estimating the proportion of pre-spawn mortality accounted for by naturally spawned spring-run Chinook salmon in the lower Feather River, given available data, is not possible.

Water temperatures may contribute to the high pre-spawn mortality estimates in the lower Feather River. High water temperatures during immigration, holding, and spawning can cause pre-spawn mortalities. McCullough (1999) stated that adult salmon, which fast during a long upstream journey, exhaust virtually all energy reserves prior to spawning. High water temperatures can increase the rate at which limited energy is consumed for standard metabolism, and can influence the rate of pre-spawn mortality. The effects to immigrating, holding, and spawning Chinook salmon from water temperature has been reviewed extensively in available literature. The effects from water temperature to spawning Chinook salmon have been discussed in this report. A discussion addressing the thermal effects to immigrating and holding Chinook salmon can be found in the interim report for SP-F10 Task 1E. Pre-spawn mortality associated with high water temperatures, in general, is a function of exposure time (McCullough 1999). Spring-run Chinook salmon enter natal rivers months prior to spawning, and hold in appropriate habitat while immigrating to spawning sites. Therefore, spring-run Chinook salmon are exposed to potentially stressful water temperatures for longer periods than fall-run strains. The cumulative effects from longer exposure to high water temperatures may increase the rate of pre-spawn mortality in spring-run Chinook, and this may contribute to the high pre-spawn mortality estimates in the lower Feather River during September. DFG reported that spring-run Chinook salmon in the Trinity River had a higher pre-spawn mortality rate (63.5 percent) than fall-run Chinook salmon (42.9 percent), and speculated that it was probably related to the added stress imposed by the extended time spent in the river (Zuspan et al. 1991). Regression analysis was used to explore the weekly pre-spawn mortality patterns of the 2002 carcass survey data from the lower Feather River. Water temperatures and spawning escapement estimates were used as the two main factors in the regression analyses. The simple models showed that mean weekly water temperature three weeks (AT3, 79.8 percent) and four weeks (AT4, 87 percent) prior to survey week was the second most influential variable in the LFC and HFC, respectively (survey week accounted for the highest percentage of variation in both reaches, but this would be expected because this variable directly reflects when pre-spawn mortality was documented). Multiple regression also found that water temperatures three and four weeks prior to the survey were influential, as noted by the *STM* model in the LFC and HFC (Table 5.11-4 and Table 5.11-6, respectively). The results from the regression analyses suggest that water temperatures three and four weeks prior to carcass detection may influence pre-spawn mortality rates. The highest pre-spawn mortality occurred during September (survey weeks 1 through 4), therefore water temperatures in the lower Feather River during August may be partially responsible. Water temperatures in the LFC during August 2002 averaged 59.2°F (15.1°C), and ranged from 55 to 61.8°F (12.8-16.6°C; Appendix B). Water temperatures in the HFC during August 2002 averaged 65.4°F (18.6°C), and ranged from 63.2 to 68.8°F (17.3-20.4°C). Water temperatures in the LFC do not appear excessively high, but in the HFC, water temperatures in August are above recommended temperatures for spawning Chinook salmon. Water temperatures and distance downstream from the Fish Barrier Dam are positively correlated in the lower Feather. In this report, water temperatures were only monitored from the Fish Barrier Dam (RM 67.25) downstream to Gridley Bridge (RM 51). Water temperatures below Gridley Bridge, in general, are higher than water temperatures above Gridley Bridge (see interim report SP-F10 Task 4B). Therefore, water temperatures below Gridley Bridge may also have contributed to the high pre-spawn mortality estimates in the lower Feather River from 2000 through 2002.

The cause of pre-spawn mortality is likely a synergistic function involving many factors. Water temperatures can invoke immediate or delayed mortalities, but can also create thermal environments conducive for other causative pre-spawn mortality factors. Many freshwater diseases that affect Chinook salmon are most virulent within specific water temperature ranges. McCullough (1999) stated that many of the diseases that commonly affect Chinook salmon become highly infectious and virulent at water temperatures above 59.9°F (15.5°C), and that both the percentage survival and time to death decrease as water temperatures increase beyond this threshold. When water temperatures are at the lower end of the infectious range, mortalities may not occur for days or weeks after exposure. Ordal and Pacha (1963) reported a 100 percent mortality rate of Chinook salmon at water temperatures of 68° F (20°C) during columnaris outbreaks, and considered temperature-induced columnaris as a major factor responsible for declines of Columbia River Chinook salmon. In 2002 in the lower Klamath River, approximately 33,000 Chinook and coho salmon, and steelhead died in September prior to spawning. The cause of death was determined to be from disease through infection from the ciliated protozoan *Ichthyopthirius multifilis* (ICH) and the bacterial pathogen *Flavobacter columnare* (columnaris) (DFG 2003). The preliminary analysis of contributing factors to this fish kill concluded that high water temperatures and low flows present in September favored rapid development of ICH. After an extensive literature review, McCullough (1999) concluded that water temperatures in the range of 55 to 59°F (12.8-15°C) appear to be least problematic for salmonids in resisting freshwater diseases. Water temperatures in the LFC during August 2002 averaged 59.2°F (15.1°C), and ranged from 55 to 61.8°F (12.8-16.6°C; Appendix B). Water temperatures in the HFC during August 2002 averaged 65.4°F (18.6°C), and ranged from 63.2 to 68.8°F (17.3-20.4°C). Water temperatures in the LFC during September 2002 averaged 53.8°F (12.1°C), and ranged from 51.9-55.9°F (11.1-13.3°C). Water temperatures in the HFC during September 2002 averaged 61.4°F (16.3°C), and ranged from 58.8 to 65°F (14.9-18.3°C). Based on available literature, it seems reasonable to suspect that water temperatures in the lower Feather River during August and September 2002 were high enough to potentially contribute to the high pre-spawn mortality estimates from 2000 through 2003. Water temperatures below Gridley Bridge in August and September were likely warmer than water temperatures above Gridley Bridge. Therefore, water temperatures below Gridley Bridge may be favorable for diseases and might have contributed to the high pre-spawn mortality estimates in the lower Feather River from 2000 through 2003. While diseases are potentially an important contributor to pre-spawn mortality, disease surveys among Central Valley salmon carcasses have found little evidence of disease-induced mortality (True 2004). An investigation of cause of death among pre-spawned salmon carcasses on Battle Creek did not find disease to be a contributing factor (pers. comm., C. Harvey-Arrison, 2004).

Multiple regression analyses identified escapement as an influential descriptor of pre-spawn mortality in both the LFC and the HFC. In many instances, mortality-causing factors are density dependent. For example, when fish are numerous diseases spread more easily and the effects are more severe. As mentioned, pre-spawn mortality is likely a function of a complex interaction among multiple factors. Fish are more easily stressed at higher population levels and crowded conditions, and are therefore more likely to die from other stressors such as high water temperatures and disease. Under certain conditions, high spawning escapement could contribute to pre-spawn mortality. DFG (2003) concluded that low flows and other flow related factors, such as fish density, caused the 2002 fish kill in the lower Klamath River. September flow releases from Iron Gate Dam in 2002 were the lowest on record when returning numbers of fall-run Chinook salmon were at average or above average levels. A combination of high water temperatures, low flows, and above average spawning returns created crowded conditions, and in turn created an environment for a disease outbreak. The fish kill in the lower Klamath River perfectly illustrates the connectivity of mortality causing factors. DFG (2003) stated that of the conditions that can cause or exacerbate a fish kill, flow is the only factor that can be controlled to any degree. To a certain degree, this also applies to the lower Feather River. The PHABSIM results suggest that the current flows in the LFC provide for adequate amounts of spawning habitat. Increasing flows in the LFC during the spawning period could potentially reduce pre-spawn mortalities by minimizing stress from crowded conditions. However, the trade-off would be a decrease in the amount of available spawning habitat and potentially a change in water temperatures. Flows in the HFC during August and September of 2000, 2002, and 2003 ranged from approximately 2,500 to 7,000 cfs, and based on the PHABSIM results, provided for approximately 20-80 percent of the maximum available habitat. Flows in the HFC during August and September of 2001 ranged from approximately 1,250 to 2,500 cfs, and based on the PHABSIM results, provided for approximately 88-100 percent of the maximum available habitat. Decreased flows in the HFC during August and September would provide more spawning habitat. However, reducing flows as a means to alleviate a density dependent problem seems counter intuitive, and the effects to pre-spawn mortality from decreased flows are unknown. Pre-spawn mortality estimates in August and September of 2000 through 2003 were similar between years, but flow differed between years, suggesting that factors other than flow are more influential to pre-spawn mortalities. In addition, pre-spawn mortality estimates decreased through time under constant flows in the LFC (this trend also occurred in the HFC from October through December), further suggesting flows may not significantly influence pre-spawn mortality rates. Escapement estimates in the lower Feather River from 2000 through 2003 are some of the highest on record, and they are much higher than estimates prior to the first year the Feather River Hatchery was in operation. Chinook salmon mean annual spawning escapement in the lower Feather River has increased since the Feather River Hatchery began operations. During the same period, suitable spawning habitat in the lower Feather River has decreased (Sommer et al. 2001). The high pre-spawn mortality estimates in the lower Feather River might be caused by a lack of suitable habitat for the high numbers of Chinook salmon returning to spawn, and this statement is supported by the high superimposition rates reported by Sommer et al. (2001). Chinook salmon returns may exceed the carrying capacity of the lower Feather River, given current available habitat and habitat quality, causing increased mortality from density dependent factors.

The lower Feather River provides a substantial and popular Chinook salmon recreational fishery. Angler effort can be quite high during the period that Chinook salmon are immigrating and spawning. Several studies have reported delayed mortalities associated with hooking, playing, and handling fish. However, information specific to Chinook salmon is lacking. Schill and Griffith (1986) examined hooking mortality of cutthroat trout (*Salmo clarki bouvieri*) in the Yellowstone River and concluded that in 1981, 3 percent of the estimated population died after capture and release by anglers. A meta-analysis of hooking mortality in non-anadromous trout was conducted by Taylor and White (1992). Mortality associated with catching trout on artificial lures and flies ranged from 1 percent to 12.6 percent, and mortality associated with catching trout using bait ranged from 14.5 percent to 50 percent. Wild trout suffered significantly higher mortalities when released after capture than did hatchery reared trout. Muoneke and Childress (1994) conducted a literature review and concluded that 6 percent to 25 percent of Chinook salmon die after capture and release. Environmental conditions, notably high water temperature and low dissolved oxygen, were important to overall mortality related to hooking, playing, and handling. Data allowing quantification of Chinook salmon mortality associated with recreational angling in the lower Feather River were unavailable. Available literature suggests that recreational angling can have measurable impacts, and it is likely that recreational angling contributes to pre-spawn mortality rates in the lower Feather River. Pre-spawn mortality resulting from recreational angling may increase during those months when water temperatures are high.

Chinook salmon undergo long and rigorous migrations en route to natal rivers. Conditions present during upstream migration, holding, and spawning contribute to pre-spawn mortality, although partitioning the magnitude of effects from each stage is not possible. The cause of pre-spawn mortality is a complex interaction consisting of multiple factors. Stress from water temperature, high spawning returns, and recreational angling are conditions that are prevalent in all three of the Central Valley tributaries to the Sacramento River (Feather River, American River, and Battle Creek) that exhibit high pre-spawn mortality. However, the relatively low pre-spawn mortality rates observed among rivers with comparable water temperature conditions, but with smaller salmon populations and less angling pressure (Yuba River, San Joaquin River tributaries), suggests that water temperatures are not the sole cause of high pre-spawn mortality observed on the Feather River from 2000 through 2003.

6.7 REDD SUPERIMPOSITION

The temporal increase in use of the LFC by spawners may be the result of a change in river flow rates over the last three decades. For example, in 1983, minimum required flows in the LFC increased from 400 cfs to 600 cfs; drought conditions during 1987-1992 caused low river flows, which could have influenced the number of spawners; and high water flow tests in the LFC in 1995 and 1996 may have influenced the number of Chinook salmon spawning in the LFC. Increased flows have been reported to attract spawning salmon (Banks 1969). Increased use of the LFC over time may also be due to habitat changes. An increase in use is typically accompanied by an increase in habitat quality or quantity. However, Sommer et al. (2001) reported that gravel quality in the lower Feather River has deteriorated to the greatest extent in the LFC, not in the

HFC. The study did not account for changes in gravel permeability. The low use of the HFC could be due to decreased gravel permeability. Hatchery operations may also account for changes in spawning habitat use by Chinook salmon in the lower Feather River. Prior to 1983, most hatchery-reared juvenile Chinook salmon were released in the lower Feather River, but post 1983 most were released in the Sacramento-San Joaquin Estuary. The change in release location may have increased survivability causing a disproportionate increase in return rates of hatchery-reared Chinook salmon. Salmon of hatchery origin are likely to have a stronger behavioral attraction to spawning locations adjacent to the Feather River Hatchery, which is located in the upper portion of the LFC (Sommer et al. 2001). An alternative hypothesis is that genetic introgression between fall-run and spring-run Chinook salmon increased spawning in the LFC. Genetic integrity for these two races historically has been maintained by differences in spawn timing and spawning locations. Dam construction has blocked spring-run access to traditional spawning locations, causing a proportionately higher overlap in spawning sites. In an attempt to maintain genetic separation, hatchery operators designate the early arrivals as spring-run. However, this approach does not appear to have been successful (Sommer et al. 2001). Brown and Greene (1994) describe coded-wire tag studies on the progeny of hatchery fish identified as fall-run and spring-run, and found evidence of substantial introgression. Brown and Greene (1994) reported significant portions of the offspring of each hatchery race returned as adults during inconsistent time peirods. For example, many of the spring-run group returned during months when hatchery operators designated all spawners as fall-run. Based on historical spawning behavior, gradual introgression of spring-run traits into the Feather River Chinook salmon population would be expected to result in an increasing preference to spawn in the uppermost riffles of the LFC, and this could cause increased incidence of superimposition.

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